An Assessment of the United States Measurement System:

Addressing Measurement Barriers to Accelerate Innovation

Appendix C

Technology Roadmap Review: Summary Report

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U.S. MEASUREMENT SYSTEM

TECHNOLOGY ROADMAP REVIEW

SUMMARY REPORT

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USMS TECHNOLOGY ROADMAP REVIEW

BACKGROUND

The U.S. Measurement System (USMS) encompasses a diverse community of private companies, national laboratories, government entities, universities, and trade organizations involved in measurement science, technology, standards, test methods, and other metrology products. The USMS is critical to the economic health of the United States, as the need for accurate measurements are pervasive throughout society. An effective measurement system enables technology innovation and strengthens competitiveness; supports strong national security and defense; and facilitates the protection of health, safety and the environment.

In the interests of enhancing U.S. competitiveness and leadership in world markets, the National Institute of Standards and Technology (NIST) is currently undertaking an assessment of the state of the USMS. The objective of the assessment is to ascertain the ability of the USMS to keep pace with and anticipate measurement needs arising from technological progress and innovation. The primary focus is on those areas where the lack of measurement capability potentially constitutes a barrier to technological innovation. For the purposes of this effort, it is assumed that technological innovation is realized when a new technology or process is introduced into the marketplace.

To support the NIST assessment of the USMS, a review was conducted of currently available technology roadmaps and other reports that describe limitations in measurement technology and/or measurement needs. These roadmaps and reports represent a diverse segment of the economy ranging from chemicals manufacture to healthcare to space travel and defense. They were developed through consensus-building activities by organizations and individuals from both the private and public sectors, and provide a broad perspective on the scientific and technical research needed to support future technological progress.

A structured methodology was designed to conduct the roadmap review and yield useful data that could be sorted in various ways to reveal trends and commonalities in measurement technology and critical measurement needs. The methodology and the results of the analysis are described in the following sections. The information gained from the review will become part of the USMS assessment, and will also be linked to an ongoing effort to develop detailed measurement needs in selected sectors and technology areas.

METHODOLOGY

The main objectives of the roadmap review were to

- Identify areas where deficiencies in measurement technology are creating barriers to technological innovation (i.e., preventing innovative products and processes from reaching the market);
- Evaluate trends in measurement needs across sectors of the economy; and
- Identify measurement needs specific to individual technical concepts or societal issues (e.g., nanotechnology, homeland security).

The review considered technology roadmaps and documents accessible through the NIST website (http://usms.nist.gov/roadmaps/), and also drew from other documents that were readily available. These included reports from the National Research Council (NRC), grand challenge reports, and other reports that were developed through a consensus-building effort with experts in the field. Most of these reports had at least some focus on future research needs. A list of the documents reviewed is provided in Appendix A.

An initial screening was conducted to identify reports that were not relevant (e.g., did not contain discussion of future research or technical needs). After this initial screening, the remaining reports were reviewed to identify the broad set of measurement needs that could potentially be barriers to technological innovation. Only measurements dealing with physical technologies were considered. The following set of data was extracted for each measurement need:

- Title of report
- Industry sector
- Industry subjects
- Technological innovation (product, process or technology) that is potentially impacted
- Specific measurement need
- Technical barrier to developing the measurement need
- Properties involved (e.g., chemical, physical, mechanical)
- Keywords
- URL
- NAICS (primary and secondary)

The above information was entered into a database to enable keyword searching. The results of this exercise are provided in Appendix B, and contain detailed information about each measurement need. Analysis was then conducted using this information to ascertain trends and commonalities along the following constructs:

- Grouping of needs specific to industry sectors, products or processes
- Cross-cuts of measurement needs across industries, applications, technologies and societal issues
- Synergies of measurement needs across sectors of the economy
- Linkages of measurement needs in roadmaps to those identified in the ongoing USMS sector, technology, discipline and SI analysis
- Mapping of measurement needs to NAICS codes (North American Industrial Classification System)

Cross-cuts, synergies, and commonalities were evaluated in various ways using keywords and property categories. Table 1 lists some of the primary search parameters used for the analysis. Some reports contained a number of measurement needs, indicating that metrology could be more critical to these technological areas, or that it was an area that has not received sufficient emphasis from the measurement community.

Table 1. Parameters for Synergy Analysis

Properties	Technologies	Concepts	Products/Solutions
Biological Chemical Physical Physiological Process/Manufacturing Variables	Lab-on-a-chip Nanotechnology Sensor Networks	Regulatory Drivers Environment Software Assurance Cyber Security Harsh Operating Environments Non-Destructive Evaluation (NDE) Threat Assessment/Infrastructure Security	Data Generation, Collection, Retrieval Standards/Reference Materials Models/Algorithms Sensors/Detectors Calibrations

SECTOR AND TECHNOLOGY ANALYSIS

The overall results of the sector analysis are shown in Figures 1 and 2. There are a large number of measurement needs in those sectors where technological advances are more rapidly and continuously emerging due to societal demands – healthcare, information technology, semiconductors, homeland security[LR1], and power and energy. The large number of measurement needs in the metals areas is primarily due to measurement challenges in areas that support metals and metal-working, specifically in welding, forging, and metal casting. The metal-supporting measurement needs also directly impact the industries where metals are a prevalent material of use, such as aerospace, automotive and heavy industrial machinery.

Figures 1 and 2 also point out some interesting findings. The semiconductor industry, for example, has limited roadmaps but a large number of measurement needs, indicating that measurements are highly important to this narrow technological area. Energy and power, on the other hand, have a large amount of measurement needs as well as roadmaps, perhaps an indication of the diversity of this sector.

Of the 213 roadmaps and reports reviewed, 49 were excluded for various reasons (were not technology focused, were not roadmaps or not applicable, were not accessible or were available only to members or at significant charge, etc). Of the remaining 163 that were found to be relevant to the study, 29 (about 18%), did not identify any measurement needs. For the most part, sectors with roadmaps that did not identify measurement needs had numerous other roadmaps that *did* identify measurement needs. For example, 4 out of the 11 aerospace roadmaps did not have measurement needs; 8 out of 32 energy/power roadmaps did not have measurement needs; and 4 out of 17 information technology roadmaps had no measurement needs. The trends in measurement needs identified for individual sectors are outlined in the following discussion. For each sector, the number of roadmap measurement needs (RMNs) and associated roadmaps are shown in brackets.

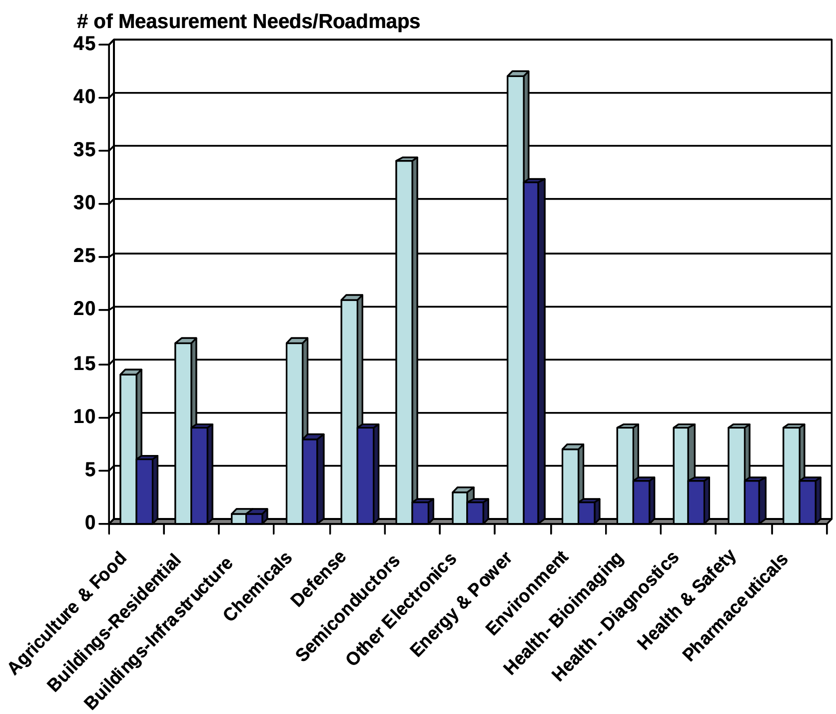

Figure 1. Distribution of Roadmap Measurement Needs In Sectors

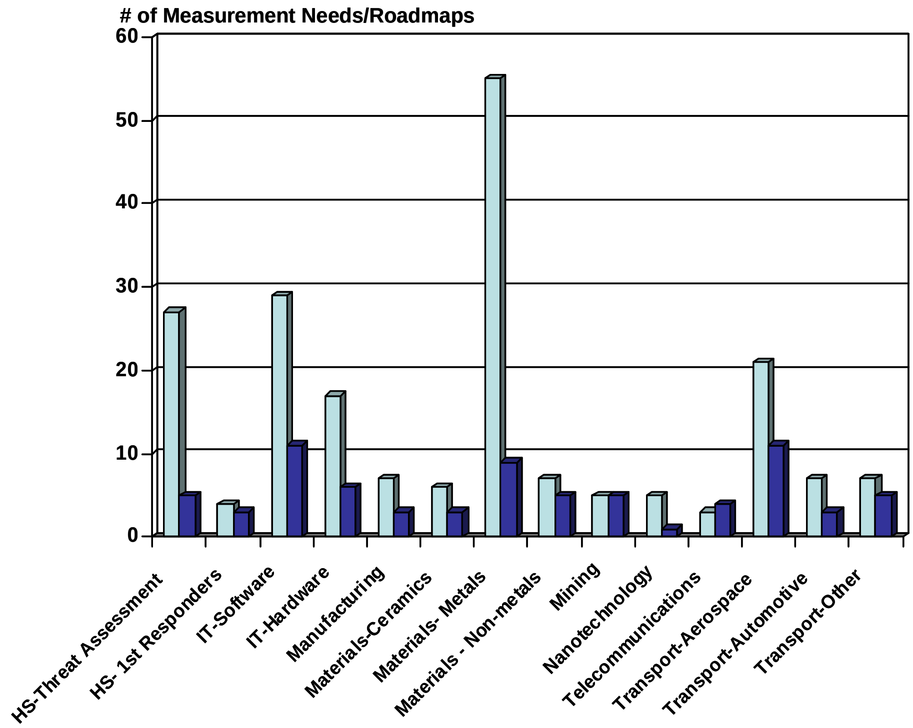

Figure 2. Distribution of Roadmap Measurement Needs In Sectors (continued)

AGRICULTURE AND FOOD PROCESSING [7 ROADMAPS, 14 RMNS]

Agriculture (crops, animals, dairy) and food and beverage processing were combined for this sector analysis. Trends in measurement needs were grouped as follows:

- *Food safety* – Metrology to ensure the safety of the agricultural and food supply, including: metrology for identification and tracking of animal species of agricultural products; detection and tracking of food borne pathogens and disease, food spoilage, and food adulteration; and tracking of food routes (e.g., tracing dairy to source cows). A range of technologies were proposed, from MEMS to nanosensors and biomarkers.
- *Food nutrition* – Metrology to better identify and analyze the nutritional properties and aesthetics of food (e.g., using bioinformatics, non-destructive evaluation (NDE), bioassays, sensors) Several roadmaps addressed food nutrition RMNs.
- *Nanoscale technology* – Sensing and detection devices operating at the nanoscale for a myriad of applications, including: detection and treatment of infection and nutrient deficiency; sensing of health problems; tracking of food pathogens and agricultural products; nanoseparation and nanobioreactors; ensuring food safety; characterizing environmental impacts/soil degradation; and creating anti-fouling nanosurfaces (e.g., packaging).
- *Sea harvesting* - Modeling, sensing and monitoring to aid in fish capture, harvesting and aquaculture, and better environmental sensing and monitoring equipment for fish farmers.

BUILDING AND CONSTRUCTION [10 ROADMAPS, 18 RMNS]

The Building and Construction sector includes commercial and residential buildings and their associated HVAC systems. Measurement needs include:

Residential/Commercial [9 Roadmaps, 17 RMNs]

- *HVAC* – Advanced building controls to enable fault detection and fine-tuning of building HVAC performance; "smart" cost-effective building sensors and transducers (controls); measurable returns for smart buildings; wireless controls; interoperability standards and protocols for smart controls.
- *Capital planning and project design* – Project management standards, product data standards, and facility assessment for homeland security (open communication standards); life cycle assessment; and metrology to support development of lightweight high-strength materials.
- *Power/energy systems* – Benchmarks for building combined heat and power (BCHP) and heat recovery (e.g., thermal versus electric; monitoring and diagnostics, intelligent controls, and standards for BCHP).
- *Lighting* – Intelligent lighting controls; sensors, metrics, and standards for lighting performance and efficiency.
- *Building envelope* – Measuring performance of the building envelope, including: prediction of losses through roofs, etc.; durability; resistance to earthquakes, moisture, etc.; methods/standards/protocols for measuring window performance in advanced window systems; standardized building components and interfaces to enable system integration of windows and other components.
- *Air quality* – Air quality monitoring (models, sensors) for environmental control, and to enable the use of new thermally activated heating technologies.

Civil Infrastructure [1 Roadmap, 1 RMN]

- *Geological engineering* – Characterization of geomedia and methods for assessing risk (subsurface characterization, time effects, rock/soil stabilization).

CHEMICALS [8 ROADMAPS, 18 RMNS]

Chemicals includes the manufacture of all chemical products, including basic organic and inorganic chemicals, industrial gases, plastics and rubber, agricultural fertilizer, herbicides and pesticides, paints and solvents, detergents, and numerous other products. Pharmaceuticals, which are listed under the same NAICS code as chemicals, are covered under healthcare for the purpose of this assessment. Ceramics and similar engineered materials are covered under "materials" in the Technology Analysis. Metrology needs emerged in four key areas:

- *Synthesis and Design* – Physical, chemical, thermodynamic, solubility and kinetic properties data and modeling/simulation tools to enable new synthesis routes and media (ionic liquids, aqueous systems, CO2 melt systems, plasmas); on-line tools for screening reactor performance; standardized data collection and protocols to support combinatorial design of chemicals and materials; metrology to support the design of nanoscale catalysts (novel imaging techniques, characterization methods).
- *Separations* – Characterization and properties of alternative separation materials and systems (adsorbents, crystallization, solvent extraction, separative reactors, bioseparators); better sensors, imaging and sampling for conventional separation systems to optimize process designs.

- *Nanomaterials* – A broad range of metrology needs are associated with the understanding, characterization, synthesis, and manufacturing of new nanomaterials: characterization tools, methods and instruments for properties measurement; tool development infrastructure; reference standards and protocols for synthesis and analysis protocols; robust manufacturing metrology; characterization, measurement and simulation probes for use during synthesis; and measurements for environmental, health and safety impacts of nanomaterials.
- *Materials of Construction* – Standardized materials of construction properties databases to enable smart equipment design; NDE of materials performance in-service (measuring/monitoring materials degradation in situ).

DEFENSE [9 ROADMAPS, 22 RMNS]

The Defense sector includes the defense industrial base (manufacturing of defense air, ground and sea transport and equipment) as well as the administration of the military and its associated installations. While there is some overlap of Defense sector needs with Homeland Security, it was possible to differentiate those particularly applicable to military systems. Measurement needs were identified in several key areas:

- *Materials* – Metrology to support new materials for a diversity of defense applications, including: development of property data for materials for energy and power, electronic and photonic materials, functional and organic hybrids, bioderived materials, and polymers; and threat assessment sensor materials (chemical, biological attack).
- *Battlefield information systems (hardware and software)* – Advanced metrology needs for battlefield operational information systems (pervasive throughout defense sector) to support advances in unmanned vehicles (both ground and air), conventional air and ground systems, and soldiers operating in the field. Key needs are standard hardware and software interfaces; highly advanced sensors to ensure accurate and timely battle space and field situational awareness (threat assessment); and interoperability standards and protocols for unmanned systems integration with global information grids.
- *Unmanned systems (ground and air)* – Measuring and monitoring flight and operational reliability; characterization of advanced lightweight materials for unmanned systems; metrology to support autonomous operation; and software assurance for perception technologies.
- *Energy systems* – Benchmarks and models to facilitate understanding and optimization of energy efficient technologies for land soldiers; performance and cost metrics for MEMS applied to military ground applications; and dynamic load measurements to simulate and optimize operations and power sources for land soldiers.
- *Military medicine* – Metrology to support development of biomaterials for variable uses in military medicine, including field monitoring of the soldier's physiological status, including: characterization of materials properties and interaction with cells and tissues; and development of biosensors and algorithms to detect and interpret specific physiological changes (e.g., heart rate, respiration, core and skin temperatures, cardiac output, blood, oxygen). Physiological sensors are also needed to support telehealth, which is growing for healthcare in general as well as military medicine.

ELECTRONICS [5 ROADMAPS, 37 RMNS]

The Electronics sector includes the manufacture of semiconductors and the devices they are used in, as well as a diversity of other electronic equipment. Measurement needs identified include:

Semiconductor [2 Roadmaps, 34 RMNs]

- *Technologies >= 45 nm* – Metrology for impurity detection, dimensional control, void and pore detection/distribution, and measurement of complex material stacks and interfacial properties; test structures and reference materials for high-kappa gate and capacitor dielectrics with engineered thin films; accurate simulation of automatic test equipment, device interface; high-speed, accurate tools for defect detection (parametric yield models, high-aspect ratio detection); metrology to promote yield enhancement (data management and test structures for rapid yield learning).

- *Technologies < 45 nm* – Metrology for real time analysis of defects in multi-layer metals; metrology and defect inspection for critical dimension measurement to 7 nm; defect inspection for patterned wafers for less than 30 nm; controlling sub-nm level processes; improved defect analysis; in-die metrology; metrology to promote yield enhancement (standard test for yield/parametric effects; detection of killer defects at high through-puts).
- *Device, material and process models for technologies < 45 nm* – Models for process variables, chemical, thermo mechanical and electrical properties of new materials, and 3-D interconnects.

- *Device, material and process models for technologies >= 45 nm* – Thermal-mechanical-electrical models for interconnections and packaging); integrated modeling of equipment, materials and feature scale processes; front-end process modeling for nanometer structures; high-frequency device and circuit modeling (5-100 GHz); simulation of current and next generation lithography; nanoscale simulation for CMOS and beyond traditional CMOS.
- *Technologies < 32 nm* – Characterization of critical material properties for charge and non-charge transport devices; modeling/simulation to predict properties of nanometer sized materials.
- *Production floor >= 45 nm* -- Metrology integration on factory floor (in situ and in line) to include sensors and process controllers, data management). *Production floor < 45 nm* -- non-destructive production-worthy wafer and mask level microscopy for dimension measurement, defect detection, and analysis; manufacturing metrology when device and interconnect technology are undefined.
- *Fundamentals* – Measurement of nanostructure mechanical properties; fault modeling to reflect real defects of new memory technologies; predictive modeling, design, characterization for beyond CMOS; characterization and metrology of nanomaterials and graded composites to support nanoelectronic design and architecture.
- *Health and safety impacts* – Rapid assessments of new chemicals to evaluate viable use in manufacturing without detriment to human health and safety.

Non-Semiconductor [3 roadmaps, 3 RMNs]

- *OLED displays* – Reliable standardized measurement tests of the optical and electrical properties of OLED displays.
- *Molecular electronics* – Metrology to support molecular electronics.

ENERGY AND POWER [32 ROADMAPS, 50 RMNS]

The Power/Energy sector involves generation of electrical power, oil and gas extraction, petroleum refining and fossil-based fuels production, and production of renewable energy (solar, wind, biomass, geothermal, hydropower). Key measurement needs identified include:

- *Bioenergy* – Analytical tools for characterization and quantification of bioproducts and bioenergy (advanced sensors, life-cycle models); real-time analysis of feedstock quality (plant, animal).
- *Carbon sequestration* – Measurement methods for accurate accounting of carbon in storage facilities (soil sequestration, geologic formations, terrestrial) and for verifying effectiveness of sequestration (geological, ocean, soil effects).
- *Coal* – Sensors and controls for emissions and combustion.
- *Combined heat and power (CHP)* – Standards and benchmarks for CHP technologies (standardized interconnection rules, micro-systems, efficiency, emissions, and reliability; controls and sensors to define system architecture, interoperability).
- *Combustion* – Low-cost, rugged, durable non-intrusive sensors for burners, boilers and industrial furnaces to provide real-time measurements (in-flame measurements, oxygen, heat flux, steam use, combustion products, temperature sensing, fuel and oxidant composition).
- *Energy recovery* – Standards for energy recovery equipment; sensors to facilitate energy source flexibility (remote sensing, process variables, product parameters); benchmarking of technologies to optimize application.
- *Hydrogen and fuel cells* – Domestic and international (interoperable) codes and standards for hydrogen use (delivery infrastructure, buildings, utility interconnection and safety, fuel cells, storage); cost-benefit analysis for electrolysis; fundamental measurement systems for solid oxide fuel cells to predict/evaluate performance.
- *Nanoscience* – Metrology to support nanostructures as energy carriers (optimized energy transport); metrology (characterization tools, theory, imaging, simulation) to link nanoscale structure and function for nanomaterial assembly and architecture with the idea of designing new materials for energy applications (mass and energy transport, storage, conversion, production); metrology and infrastructure to support scaleable synthesis of nanomaterials for unique energy applications; metrology to support use of carbon nanotubes for hydrogen storage.
- *Nuclear* – Detectors and sensors for hydrogen and oxygen in nuclear shipping/storage containers; modeling and diagnostics for fusion plasmas; measurements and standards for physical, neutronic, thermal, and tensile properties and degradation of materials for nuclear power reactors; traceable neutron dosimetry protocols for nuclear power and radiation protection.
- *Petroleum* – Measurement techniques, controls and sensors for on-line real time non-intrusive analysis of stream compositions, equipment condition, and processing in petroleum refineries; measurements and data to support improved environmental performance (risk assessment, fugitive emission detection, site contamination) in refineries.
- *Photovoltaics (PV)* – Uniform net metering and interconnection standards for solar power; advanced process controls and in line diagnostic tools to improve PV manufacturing speed and quality; standards for module electrical interfaces and PV system components.

- *Power generation and transmission* – Improved control of the grid; wide area measurement systems (sensors and measurement technology) for smart power delivery; real-time condition assessment of advanced power systems (components, emissions, outputs).
- *Wind* – Noise measurement standards for wind turbines.

ENVIRONMENT [2 ROADMAP, 7 RMNS]

This category covers technology and industries related to environmental protection, waste management, waste water treatment and management, and pollution abatement and control. Environmental issues arise, however, in numerous roadmaps and are pervasive throughout the industrial sector. Measurement needs include:

- *Nanotechnology* – Characterize nanometer-sized zeolites and nanostructures for use as environmental catalysts; metrology to support development of dispersed suspensions of nanoparticles without absorbed additives.
- *Water supply management* – Better identification of contaminants in treated wastewaters, and lower analytical detection limits for contaminants; sensors to assess membrane integrity in desalination to prevent pathogen release; metrology to monitor wastewater particulates based on size and shape to provide early pathogen warning in real time.

HEALTHCARE [9 ROADMAPS, 37 RMNS]

For the purposes of this review, the Healthcare sector includes all medical procedures, medical equipment manufacture and use; pharmaceuticals research, manufacture, and use; and all other products and services related to the practice of medicine. Military medicine is covered under the Defense sector. Some roadmaps covered more than one of the areas below. Emerging critical measurement needs include:

Bioimaging and Informatics [4 Roadmaps, 9 RMNs]

- *Bioimaging/Medical Imaging* – Medical imaging for tumors to evaluate volume and responsiveness to treatments; radiography and fluoroscopy standards to enable use of X-ray flat-panel imagers; standard data structures to enable comparison of images across sites and jurisdictions; and better imaging for early patient risk detection.
- *Information systems* – Standardized, interoperable networks and seamless data reporting systems to capture patient outcomes, clinical research, technology performance, and other important data for practical and research use.

Clinical Diagnostics [4 Roadmaps, 9 RMNs]

- *Early detection systems* - Analytical tools for ex vivo diagnostics and other early detection platforms (rapid analysis of body fluids and gases, and high-throughput systems for single molecule detection).
- *Cell/stem cell therapies and research* – Characterization procedures and standards for stem cells and bioengineered tissues, and molecular and high-resolution cellular probes.
- *Nuclear medicine* – Standards and measurements for radioactive isotopes, medical dose mapping systems for 3D conformal and intensity modulate radiation therapy, increased sensitivity instruments and standards for radiation protection.

Health and Safety [4 Roadmaps, 9 RMNs]

- *Medical device manufacture* - Sensors to monitor and control processes; standards and tools (genomics, proteomics, bioinformatics, medical) to improve medical device development process and detect safety issues.
- *Nanomedicine* – Several roadmaps cited the following priorities: metrology to support nanomedicine, including compatibility of nanomaterials with the body; understanding of bottom-up assembly of biological nanosystems; and advanced imaging, sensors and probes to assess molecular, biological, and cellular response at the nanoscale.
- *Telehealth* – Telehealth represents a new paradigm in medicine, and a myriad of measurement needs are emerging along with it: industry-wide telehealth standards (data integrated with medical protocols), which are critical for interoperability and integration across many systems of communication and data manipulation; and standardized tools to measure clinical efficacy of telehealth.

Pharmaceuticals [4 Roadmaps, 10 RMNs]

- *Drug manufacture* – Updated standards and practices for drug manufacture to improve quality control and increase safety (current good manufacturing practices have not been updated in 25 years).
- *Drug discovery and development* – In vivo and in vitro drug release testing methods and apparatus to determine and measure performance, behavior, particle sizes, dispersion, and release. rates, stability, degradation, and safety to aid in approval of new parenterals; smart sensors based on chemical and physiological signals to enable better drug release; and metrology to aid in modeling human immune responses, tissue and organ responses, the time course of diseases and drugs, proteomic and metabolic behavior.

HOMELAND SECURITY [6 ROADMAPS, 31 RMNS]

Homeland Security, while not a specific sector of the economy, was analyzed because it is critical to all sectors of the economy. Innovations in Homeland Security are essential to the health, safety, economic progress, and competitiveness of many critical U.S. infrastructures. Five roadmaps focus directly on Homeland Security and issues of Homeland Security are discussed at some level in a large number of the roadmaps reviewed. Critical needs in metrology encompass primarily advanced sensors and detection systems for threat assessment, standards and protocols, and capitalizing on advances in nanotechnology and biotechnology. Key needs for metrology related to Homeland Security include:

Threat Detection and Protection [5 Roadmaps, 27 RMNs]

- *Biological and microbiological, chemical, radioactive and explosive threat detection* – Sensors, detection systems for safety of food and agriculture; protection against biological attacks (sensor early warning systems); rapid detection systems (structural, nucleic-acid based, chemical-based, function-based); optical sensors for threat detection; detection of hand-held radioactive devices, radiation detection and decontamination, and tracking of radioactive particles after attack.
- *Terrorist agent screening* – Screening at airports, borders (recognition of behavioral and physiological changes and perceptions, biometric identification).
- *Nanotechnology*– Highly advanced nanosensors and devices for detection of chemical, biological, radiological and explosive elements; nanomaterials for advanced protective clothing and filters and remediation of attacks.

- *Building and personal protection* – Materials properties characterization (structural materials with protection against threat agents), sensor defense systems, facility vulnerability assessments, infectivity models, standards for security-hardened building protection systems; properties of next generation personal protection materials, performance based codes and standards for new structures.
- *Cyber security* - Metrology for software assurance, security assessment, wireless security, load and volume monitoring, cyber intrusion detection, software vulnerability assessment, and tracing origin of attacks.

First Responders [3 Roadmaps, 4 RMNs]

- *Telehealth* – Sensors and surveillance devices to improve homeland security alert capabilities – chemical, radiological, biological – and to support links to telehealth systems that respond to attacks.
- *Attack response* – Impact monitoring for the aftermath of biological, chemical, and nuclear attacks; better fire sensors, including personal fire sensors.
- *Fire safety* – Tools, methods, and guidelines for measuring fire properties to enable better fire safety models; measurement and imaging techniques to understand wildfire behavior (fuel characterization, fire emissions, combustion chemistry, visual imagery of fire spread, remote sensing, generation of wildland fire fuel maps).

INFORMATION TECHNOLOGY [16 ROADMAPS, 50 RMNS]

The Information Technology sector is comprised of computational tools, models, data management systems, packaged software, software assurance, computers (but not semiconductors) and related equipment and hardware, quantum computing, and the Internet. Semiconductor manufacture is covered separately under Semiconductors. Some roadmaps covered both software and hardware technology issues. Specific measurement needs include:

Software [11 Roadmaps, 33 RMNs]

- *Software/hardware performance and assurance* – Benchmarks for certifying software and reliability, productivity and high confidence computing based on quantitative criteria; performance modeling methods and templates; metrology to support trustworthy software analysis, development and engineering, including direct evaluation of software artifacts; rigorous tools for analyzing system and software behavior for high confidence applications (automated verification, validation, simulation of behavior).
- *Internet technology* – Standards and protocols for security, redundancy and transport; improved information retrieval systems.
- *Software and computing security* – Metrology to assess, verify and validate software vulnerability; security metrics and benchmarks on global or localized level; methods for tracing cyber attacks.
- *Quantum computing* – Standards for quantum key distribution (quantum cryptography); measuring and fully characterizing qubits (spectral density of noise generators, fidelity of state preparation and single/two/three qubit logic operations, fidelity and correlation of GHZ and W states, scaling of decoherence rates, preparing Bell states, entanglement swapping, etc.); standards for fabrication of qubits and associated circuitry; understanding, measuring and controlling decoherence; achieving single-nuclear-spin detection, measurement and control;

measurements to support neutral atom and linear optics quantum computing; instrumentation for noise measurement and tomography.

Hardware [6 Roadmaps, 17 RMNs]

- *Supercomputer performance* – Real-time monitoring for detection, diagnosis, and prognosis of malfunctions and failures, including sensor and actuator calibration for safe control of physical systems; improved ability to measure time to solution (estimating activities involving human effort, measuring programmability, program preparation and setup, debugging, downtime, background interrupts, etc); benchmarks for certifying system reliability.
- *Geospatial and positioning systems* – Metrology to support mobile environments and location-sensing computing infrastructures; predictive models and data mining methods with better spatial and temporal capabilities; methods and algorithms for information perceptualization (multivariate, multiscale, time-variable).
- *Data management, storage and retrieval* – Measurements to improve and evaluate information retrieval from web pages and databases; enhanced query capability and standards to support large sensor networks (i.e., ability to adapt to rapidly changing configurations, tagging every object with a sensor, pervasive storage for sensor networks); standards to prioritize operations and for open application programming interfaces; detection and discovery of complex relationships in storage systems.
- *Autonomic (self regulating) computing systems* - Benchmarks for autonomic (self-regulating) computing; and methods to compare data storage systems on their ability to optimize, configure, heal and protect themselves.

MANUFACTURING [2 ROADMAPS, 4 RMNS]

Manufacturing for this purpose covers those roadmaps that discussed measurement needs in more cross-cutting ways that were not specific to an industrial sector.

- *Product design and optimization* – Models and standards to support product design and optimization, from requirements definition to product delivery; models and economic measurement techniques for direct measurement of product quality to enable better closed loop control.
- *Processes* – Models, life-cycle analysis and certification procedures to support manufacturing processes and materials; robust, non-intrusive, rugged sensors and controls to optimize process heating systems; automated maintenance and diagnostics to identify abnormal situations during manufacturing.
- *Energy use* – Uniform metric for predicting energy use and savings.

MATERIALS [17 ROADMAPS, 68 RMNS]

The Materials sector is a cross-section of primary metals (steel, aluminum) and associated manufacturing casting, machining and fabricating processes; ceramics used as coatings, catalysts, refractories, or for other purposes; other non-metallic materials such as concrete, paper and associated pulping processes; glass; and polymers. Some portion of polymers (monomer synthesis) are covered under chemicals manufacture; fabrication/testing of polymers is covered here. Measurement needs for each category include:

Ceramics [3 Roadmaps, 6 RMNs]

- *Coatings* – Improved methods for measuring coating characteristics and properties (adhesion, thermal conductivity, wear resistance); standards and specifications for coating materials and processes; in-line inspection methods and sensors to enhance process control and automation.
- *Advanced ceramics* -- In-line, rapid, non-destructive, inspection methods and sensors to enhance continuous process control and automation in fabrication and post-process; test standards in support of ceramic-metal composite properties.

Metals [9 Roadmaps, 55 RMNs]

- *Powder metallurgy* – Fundamental particulate science to characterize new and existing powder metal materials and processes (property-structure-performance, process-microstructure relationships, thermophysical data, porosity properties, prediction of properties from microstructure, etc); more sophisticated sensors, controls, models and diagnostics for powder coating materials, parts and processes for process optimization and control.
- *Welding* – Reliable, real-time, non-destructive weld inspection technologies for weld conditions, fitness for service, weld life, defects, dimensions, quality control; knowledge management systems that merge welding requirements/data with industry/process data to support integrated welding across manufacturing cycles; welding solution database with properties and characteristics of welds and welding materials with history of solutions; machine controls based on welder hand motions.
- *Alumina* – Rugged sensors, controls and instrumentation for use throughout the alumina refining process to enable automation and optimization; modeling and simulation to test new reagents for the Bayer process; tools and models for full life-cycle and process management.
- *Aluminum* – Metrology to support primary production (electrolytic cells); metrology to support melting, solidification, and recycling of aluminum (physical phenomena, temperature, structural properties, oxidation mechanicals, melting/casting characteristics), including advanced ceramic sensors; metrology to support fabrication (relating structural properties to manufacturing); metrology to support alloy development and finished products (alloy composition and processing and properties, integration with products and processes); baseline measurement system for the complete aluminum production process to compare use of new materials in manufacturing equipment (e.g., ceramics).
- *Forging* – Real-time, non-destructive sensors for forging; real-time hot-dimensional measuring capability; robust sensors for measuring vibration, acoustics, strain and other variables in a high-temperature environment.
- *Metal casting* – Materials property data on cast alloys for improved metalcasting design (wrought equivalency data, bulk mechanical and physical properties, fatigue behavior, etc); metrology to support design-process relationships (microstructure and residual stress effects on machinability, prediction of casting properties and performance, modeling of solidification processes in the mold); sensors and models to support innovative and intelligent cast processing to improve quality and reduce scrap; characterization tools to enhance competitiveness (integration of design with material properties); metrology to support reduction of variability in castings (standards for casting acceptance, smart measurement devices for casting, contamination effects, role of gravity).

- *Steel* – Sensors and process models for ironmaking (blast furnace, smelting); on-line data for cokemaking operations; robust process sensors and models for steelmaking, specifically for process variables; sensors and controls for ladle refining and steel casting; characterization of steel rolling and finishing process variables; steel refractory sensing and modeling tools to improve design of steelmaking vessels and reduce manufacturing costs; real-time process monitoring and analysis of steel container manufacture; data, guidelines and limits for steels used in construction and automobile applications (bending, forming, yield strength, ductility).

Other Non-Metallic Materials [5 Roadmaps, 7 RMNs]

- *Concrete* – Metrology to continuously monitor product durability and property performance during production (NDE, sensors, intelligent curing, computer-integrated knowledge/sensing systems); measurements and models to predict performance in-service (corrosion, cracking, composition over time, self-desiccation); embedded sensors and smart materials to monitor, predict and adjust to conditions, including environmental interactions; comparative tests and data to enable comparison of alternative reinforcement materials.
- *Glass* – Durable, online sensors and feedback controls to automate coating processes for all types of glass and enable mass production with lower defects and higher quality; sensors to provide real-time data on conditions in the glass melt and the combustion atmosphere in the furnace for real-time process adjustments.
- *Pulp and paper* – Methods to gather, analyze and present environmental and energy efficiency data.

Polymers [covered under chemicals]

- *Polymer and composite development* – Sensors, imaging techniques to support materials characterization (composition, structure, dynamics,) and behavior (aging, tribology, stress cracking, composite performance); on-line continuous monitoring of process parameters during fabrication.

Mining of Materials [5 Roadmaps, 6 RMNs]

- *Geologic sensors and imaging for extraction* – Ways to sense, visualize, interpolate, model and predict anomalies in front of mining equipment and material ahead of the working face; in-line sensors and controls to accurately predict location and quality of mineral resources; high-resolution sensing and imaging to quantify metal/mineral value and reduce drilling, blasting, crushing.
- *Separations* – Measurement systems and control sensors for extraction and purification of ores (optical sorting, real-time particle size analysis, in situ spectroscopy and interaction force measurements); characterization and modeling of flotation other processes.

NANOTECHNOLOGY [10 ROADMAPS, 49 RMNS]

Nanotechnology is a broad category covering all aspects of the use of nanoscience. Nanoscience is being applied to many fields and economic sectors, and there are consequently overlaps. Forty-nine (49) measurement needs were identified as applying to nanoscience (excluding measurement needs in NIST roadmaps). The economic sectors expressing measurement needs in nanotechnology include:

- Aerospace
- Agriculture and food processing
- Aluminum
- Electronics
- Energy and power
- Environment

- Chemicals
- Defense (equipment and medicine)
- Healthcare (diagnostics, bioimaging)
- Homeland security

The distribution of RMNs for nanotechnology in these sectors is shown in Figure 3. Topics that emerged across various sectors include:

Standards, protocols and reference materials

- Standards and reference materials for synthesis of nanomaterials
- Microsystem manufacturing standards
- Protocols for characterizing environmental and health effects

Metrology for design and synthesis of nanomaterials for new applications

- Aluminum alloys
- Aerospace components
- Defense air and land vehicles
- Biomaterials
- Energy carriers
- Catalysts
- Intelligent design and tools to accelerate systematic nanomaterials design

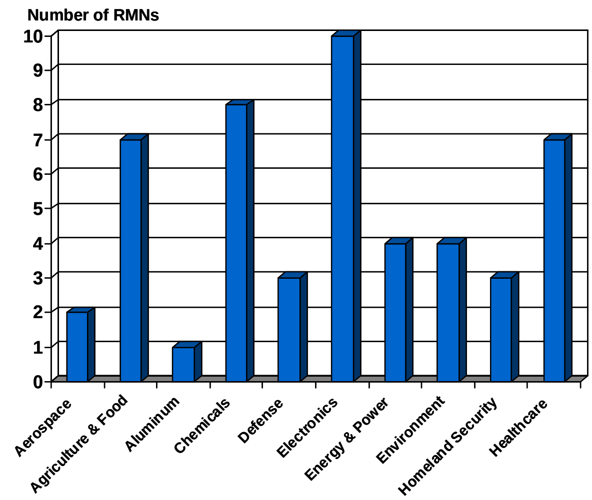

Figure 3. Distribution of RMNs for Nanotechnology Among Sectors

Manufacturing and processing of nanomaterials

- Modular tools for integrated synthesis and assembly
- Device modeling
- Front end process modeling
- Complimentary metal oxide semiconductor (CMOS) simulation

Characterization and modeling of nanomaterials

- Measurement and simulation probes for nanoscale properties
- Characterization of environmental and health effects
- Characterization of structure, function, chemical, physical properties, scalability, and quality
- Linking of nanoscale structure and function
- Interface/surface characterization
- Nanoparticle characterization of transition metal carbides and oxycarbides, nano-sized zeolites and nanostructures, and nanoparticles in soil, air and water
- Electronic properties
- Characterization of graded composites
- Nanomaterial mechanics
- Measurements to support multi-scale modeling
- Study of biological nanosystems and compatibility between biological and non-biological nanomaterials

Metrology to support nanodevices

- Sensors, detectors, nanoseparators, molecular electronics, bioanalytical nanosensors, pollutant detectors, pathogen and nutrient detectors, nanothermal devices, identify preservation and tracking, nano devices to treat infection and nutrient deficiency, nanodevices for molecular and cellular biology, medical diagnostic testing.

Threat detection and protection

- In vivo sensing
- Chemical, biological and radiological sensing
- Nanostructures for selective adsorbents and protective materials
- Nanostructures for high-performance structural materials (protection against attack)

Figure 4 illustrates the distribution of RMNs across categories. The majority of measurement needs were in the development and manufacture of characterization tools, and these encompassed virtually every property and attribute of nanomaterials. The primary objective of these measurement needs was not to enhance fundamental understanding of nanomaterials, but to be able to understand the link between properties and functionality and ultimately tie that to performance and specific production applications. A lesser but overarching priority identified was to characterize and understand the environmental, biological and health impacts of using nanomaterials.

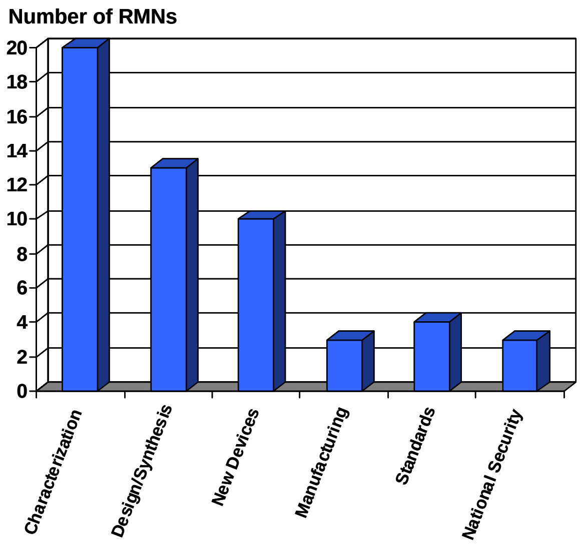

Figure 4. Distribution of RMNs in Nanotechnology

Design and synthesis had the second largest number of RMNs. The lack of sufficient metrology to aid in the design process and to support development and synthesis was cited as a key stumbling block to the future use of nanomaterials in a number of roadmaps. Characterization, design and synthesis are closely linked to and directly support manufacturing of actual nanodevices; resolving metrology issues in these pre-production areas was often stated as being critical to moving forward with development and manufacture of working devices.

TELECOMMUNICATIONS [4 ROADMAPS, 4 RMNS]

Telecommunications encompasses all networks, equipment and systems used for the transmission and communication of audio and other signals over long distances. Key measurement needs include:

- *Optical communications* – Measurements and standards for optical communications equipment and software, including security standards.
- *High speed communications* – Standardized secure high speed communication systems for world-wide sharing of the generation of high energy physics experiments and data.
- *Wireless* – Ability to predict quality of service from wireless sensor networks.

TRANSPORTATION [19 ROADMAPS, 42 RMNS]

Aerospace is defined as research, design and manufacturing of commercial aircraft as well as space craft, and all related products and services. Defense air systems are covered separately under the Defense sector. Automotive includes the manufacture of automobiles, trucks and advanced systems for powering vehicles (e.g., fuel cells). The "Other" category encompasses rail and sea transport. A majority of measurement needs in aerospace focused on spacecraft and space travel. Measurement needs include:

Aerospace [11 Roadmaps, 26 RMNs]

- *Space travel, science and space craft* – Measurement technology to enable control of the space craft internal environment and safety of crews in space, and enable stellar positioning.
    - *Microgravity environments* - Fundamental physics measurements (gravitational, relativistic, laser cooling, atomic, low-temperature, condensed physics); predictive capabilities and control (particle aggregation and dispersion, phase change and flow, flow through porous media and components, stability dynamics); techniques to predict proper contact angle at free surface/solid junction; characterization of fire signatures, solid waste monitoring and control, and empirical correlations for thermal systems to enhance crew safety and environment.
- *Air travel and associated infrastructure* – While several roadmaps were available for aviation, only a few measurement needs were noted. Those that did emerge emphasized the need for standards to reduce or help regulate noise and air emissions (two roadmaps). Detection of threats (hazardous items, chemical or biological agents) and standardized screening methods were also a priority.

- *Aircraft welding and machining* – Priorities include reliable inspection technologies (NDE) for welds to enhance quality, performance and fitness-for-service, and associated standards; and better scientific understanding and modeling of welds to shorten time between design phase and production.
- *Nanoscience* – Metrology to support use of nanomaterials in aerospace composites.

Automotive [3 Roadmaps, 7 RMNs]

- *Welding* – Robust, non-destructive weld inspection processes for reliability and quality, and fitness-for-service in high-volume automotive applications.
- *Manufacturing and assembly technology* – Advanced sensors for harsh environments; automated assessments; process models; standards for electronic components/electronic manufacturing services providers.
- *Fuel cells* – Metrology to characterize fuel cell reliability and performance; sensors to detect hydrogen leaks; codes and standards for fuel cells and hydrogen storage and distribution.
- *Environmental performance* – Controlling/understanding combustion; sensing technologies for pollutant and microbial detection of particulates (on-board, real-time); nanoscale characterization of new catalytic converter materials; test methods for rapid aging and screening of new emission-reduction catalysts.

- *Fuel efficiency* – Measurement technology to optimize fuel type for specific applications; standards for uniform connector and power levels at truck stops to address anti-idling.

Other [4 Roadmaps, 7 RMNs]

- *Rail* – Emissions sensors for locomotives to measure NOx and particulates and enable closed loop control systems.
- *Marine* – Sensors for non-contact characterization of sea port bottoms; sensing and measurement for marine communications (remote radar, underwater acoustics, bathymetric mapping of St. Lawrence beds, etc.); schemes for collection and analysis of complex data streams for conditions at and below the seabed and at sea surface to support a marine geospatial data infrastructure with remote access capability.
- *Transportation security* – Security protocols for information systems to ensure confidentiality and integrity of information assets.

PROPERTIES ANALYSIS

Roadmap measurement needs related to specific properties were reviewed in five areas to identify trends across sectors and specific applications. The distribution of RMNs for the properties reviewed is shown in Figure 5.

Chemical and physical properties represent the largest focus of measurement needs. These are broad categories that actually reflect a diversity of properties. In terms of RMNs, there are also overlaps between the categories. One RMN, for example, might identify the need to measure process variables as well as chemical properties. Trends for each category are discussed below.

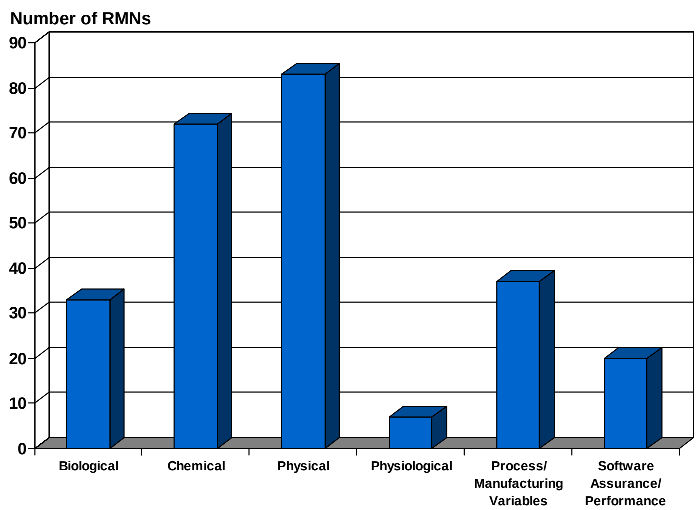

Figure 5. Distribution of RMNs Among Selected Properties

- *Biological* – Needs for better biological measurements were identified in healthcare, nanotechnology, Homeland Security, agriculture and food processing, defense, and environment. Key technology or application areas included clinical diagnostics (in vivo, bioimaging), nanomedicine (biocompatibility of nanomaterials in the body), environmental health and safety (water contamination, exposure), biological threat detection and biosurveillance (food, agriculture and Homeland Security), and molecular function.
- *Chemical* – Chemical measurement needs were pervasive throughout many sectors and technology areas, including chemicals, aluminum, defense, food processing, nanotechnology, Homeland Security, metals manufacture, healthcare and medicine, semiconductors, and the environment. Key areas to be addressed by measurement needs included product quality and performance, process monitoring, safety of food and pharmaceuticals, chemical threat detection, chemical synthesis and reactor design, environmental impact assessment, fire suppression and

detection, and all types of materials design and development. In many cases, the need for chemical property measurements was listed along with the need for an entire suite of property measurements (e.g., physical, biological, thermal, biological, photochemical, magnetic, radiological, etc).

- *Physical* – Measurement needs for physical properties were identified in chemicals (separations, process design, nanomaterials), automotive, aerospace, building technology (structural materials), defense (materials), healthcare (drug delivery, materials development), homeland security (protective materials, threat detection), metals (machinability, performance, life, characteristics, process design and optimization, yield improvement), nanotechnology, power and energy, and semiconductors.
- *Physiological* – Healthcare, homeland security and defense all identified the need to measure physiological properties. All cited sensing technology as a key measurement need. Applications included drug delivery, teleheatlh, military medicine, and monitoring of physiological or behavioral changes.
- *Process/Manufacturing Variables* – Numerous sectors identified measurement needs for better control and optimization of manufacturing processes and to improve product quality and yield. These included chemicals, healthcare, metals (steel, aluminum, powder metals, welding, forging), and non-metallic materials (ceramics, paper, nanomaterials, concrete). More than half (62%) of RMNs for processing were in the materials area, with 43% in metals and 19% in non-metallic materials. The remainder of RMNs focused on monitoring and control of combustion and process heating, and general optimization of manufacturing through accurate data collection feeding into simulation or inferential control models.

CROSS-CUTS AND COMMONALITIES

The roadmaps were reviewed to identify cross-cuts and areas of common interest across most of the economic sectors, from the perspective of technologies, measurement solutions, and properties to be measured. The results of this exercise are shown in Table 2. Some of the major trends are discussed below, with the exception of nanotechnology, which is discussed earlier in the report under the sector/technology analysis.

TECHNOLOGIES/CONCEPTS

The following major trends emerged from the analysis of technologies and concepts:

- *Threat assessment* – The need to accurately assess threats (chemical, biological, microbial, radiological, explosive, cyber) was identified as a primary measurement need in many economic sectors, in addition to those voiced directly by the Department of Homeland Security. The chemicals sector notably did not identify measurement needs in this area, although they have many, because most of their roadmaps were completed prior to or near 9/11. Nanotechnology (e.g., nanosensors, nanomaterials) was mentioned in several roadmaps as a potential technology solution.
- *Software assurance/security* – Homeland security, defense, telecommunications, transportation, and information technology all identified measurement needs for software assurance and security. Most of the RMNs were in information technology (67%), with the primary objectives of addressing software assurance, vulnerability, security, reliability, confidence, and quality. Similar objectives

were cited by defense, homeland security and transportation. Internet or cyber security accounted for 44% of RMNs in this category, and was cited as a need by both the information technology community and homeland security. Hardware and software standards and interfaces were cited as needs by both defense and telecommunications.

Table 2. Matrix of Roadmap Measurement Needs: Synergies Across Economic Sectors

	Agriculture & Food	Buildings & Construction	Chemicals	Defense	Electronics/Semiconductors	Energy and Power	Healthcare	Homeland Security	Information Technology	Materials	Nanotechnology	Telecommunications	Transportation: Aerospace	Transportation: Automotive
Technologies/Concepts														
Cyber Security						X		X	X					
Environment	X	X					X				X		X	X
Harsh Operating Environments			X			X		X		X				
Lab-on-a-Chip	X		X		X		X						X	X
Nanotechnology	X		X	X	X	X	X	X	X	X	X		X	X
Non-Destructive Evaluation	X		X	X	X	X				X	X		X	X
Regulatory Drivers	X	X	X		X	X	X	X		X	X		X	
Sensors Networks						X	X	X	X			X		
Software Assurance				X				X	X			X	X	
Threat Assessment/Infrastructure Security	X	X		X		X	X	X	X			X	X	
Measurement Solutions/Products														
Data Generation, Collection, Retrieval			X		X	X	X		X	X				
Standards and Reference Materials		X	X	X	X	X	X	X	X	X	X	X	X	X
Models/Algorithms	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sensors/Detectors	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Calibrations			X		X	X	X		X		X			
Properties														
Biological	X			X			X	X						
Chemical	X		X	X	X		X	X		X	X			
Physical		X	X	X	X	X	X	X		X	X		X	X
Physiological				X			X	X						
Process/Manufacturing/Production Variables			X			X	X			X	X			

- *Regulation* – Regulation was found to drive measurement needs in ten out of the fourteen sectors shown in Table 2. The key regulating agencies behind the RMNs identified were the Food and Drug Administration (FDA), Federal Aviation Administration (FAA), Environmental Protection Agency (EPA), Federal Energy Regulatory Commission (FERC), Nuclear Regulatory Commission (NRC), and federal/state bodies involved with developing and enforcing building regulations and codes. About half (48%) were related to measuring environmental impacts (air, land, water). Food and drugs represented another large category (17%).

- *Lab-on-a-chip sensors and devices* – This technology was cited by various sectors (chemicals, aerospace [space], agriculture and food) for use in environmental and other types of monitoring or analytical measurement tools. The potential for cross-pollination was not entirely clear. Most needs were directed toward single molecule events and the detection of biological and chemical species.
- *Production environments* – The ability to make non-intrusive, non-destructive measurements of production and process variables was cited by most of the manufacturing sectors. Most of these RMNs were specific to the industries involved. Many originated from the need to inspect the integrity of equipment or product quality. In some cases, measurements would need to be made in harsh operating environments (high temperature, pressure, corrosive), notably in the chemicals, energy, and metals industries (forging, steel, welding, powder metallurgy).
- *Sensor networks* – Wide area measurements and the need for dynamic sensor networks emerged in a number of sectors: energy and power ("smart" power delivery), information technology (standards for data storage from dynamic sensor networks), telecommunications (measurement of wireless sensor network performance), Homeland Security (chemical, biological, nuclear, and other threat assessment), and healthcare (teleheath, or monitoring of agents that could potentially harm human health). There are some synergies among these needs. For example, data storage and enhanced query capabilities will be critical for wide area measurements for the power grid as well as other applications.

MEASUREMENT SOLUTIONS/PRODUCTS

Specific measurement products were tabulated across sectors and technologies to determine the areas of greatest concentration within RMNs. Only five product areas were considered:

- Data generation, collection and retrieval
- Standards and reference materials
- Models and algorithms
- Sensors and detectors
- Calibration

The results of the tabulation are shown in Figure 6. Sensors and detectors represent the largest category of RMNs, although significant numbers of measurement needs were identified in all categories except for calibration. Table 3 provides a breakdown of measurement products by economic sector or technology area.

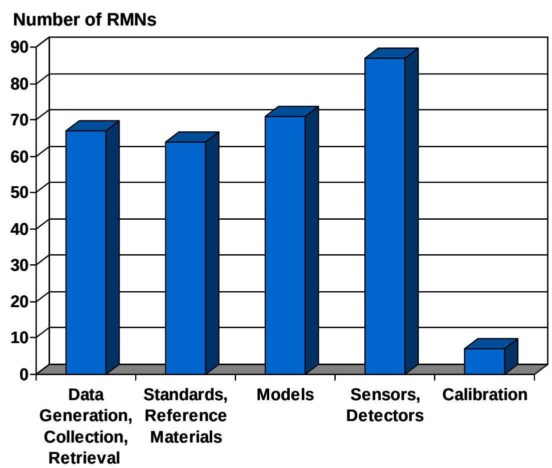

Figure 6. Distribution of RMNs for Measurement Solutions, Products and Services

Data generation, collection and retrieval was cited as a need in most sectors, with materials (27%), information technology (19%), chemicals (12%), and healthcare accounting for larger shares (9%). The need for standards is distributed relatively uniformly across sectors. Predictive and other types of models were cited notably in materials (27%), electronics/semiconductors (19%), and information technology (17%). Sensors and detectors are also needed across numerous sectors, with larger concentrations in energy and power and materials manufacture.

Table 3. Measurement Solutions/Products by Sector/Technology Area					
Sector/Technology	Data	Standards	Models	Sensors	Calibration
Agriculture and Food Processing	1		1	5	
Building and Construction					
Residential/Commercial	3	7	1	3	
Civil/Infrastructure	1				
Chemicals	8	3	2	3	1
Defense	4	3	6	7	
Electronics					
Semiconductor	4	4	13	1	
Non-semiconductor		2			
Energy and Power	2	8	2	12	
Environment			1	2	
Healthcare					2
Bioimaging and Informatics	2	3	2	2	
Clinical Diagnostics	3	4			
Health and Safety		2		3	
Pharmaceuticals	1				
Homeland Security					
Threat Detection and Protection	2	5	4	9	
First Responders			1		
Information Technology					
Software	7	6	12		3
Hardware	6	1		3	
Manufacturing	1	1	4	3	
Materials					
Ceramics				2	
Metals	14	5	18	18	
Polymers					
Other Non-Metallics	4	2		3	
Mining of Materials			1	4	
Nanotechnology		1		1	
Telecommunications		1			
Transportation					
Aerospace	1	3		2	1
Automotive	1	2	1	2	
Other	2		1	2	
Other		1			
TOTAL	67	64	70	87	7

NAICS MAPPING

To provide another perspective, the roadmap measurement needs identified for this effort were mapped onto North American Industrial Classification Systems (NAICS) codes which are assigned to each sector of the economy by the Department of Commerce.   These codes are utilized primarily for the gathering of economic and other data.

Figures 7 through 10 illustrate some of the results of the NAICS mapping. The bulk of the charts resulting from this exercise are provided in Appendix C. Assigning the RMNs to NAICS codes does not provide the most complete view of the sectors studied, for various reasons. For example, the NAICS classifies medical equipment under manufacturing, pharmaceuticals under chemicals, and general healthcare under a service category. To more practically view measurement needs in this area would require a combination of these categories, pulling from different major classifications. Consequently, for this report, those areas were not grouped according to NAICS, but as a single category called Healthcare which more adequately describes the user community of the measurement technologies.   Similar issues arose with other sectors where the actual community of users was spread across various NAICS codes.

However, the NAICS mapping does provide some useful information in that it shows the sectors of the economy where most of the measurement needs are occurring from a census standpoint.

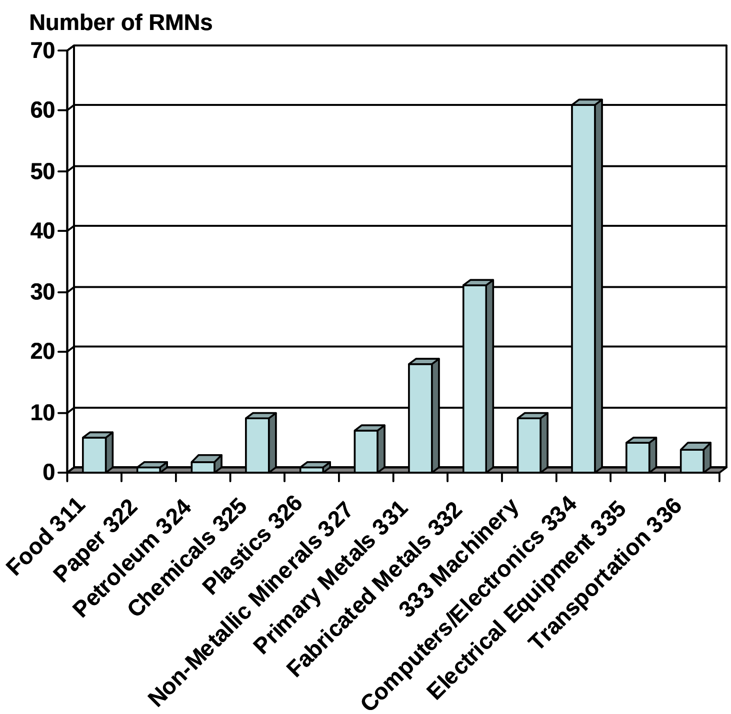

Figure 7. Roadmap Measurement Needs by 3-Digit NAICS Codes

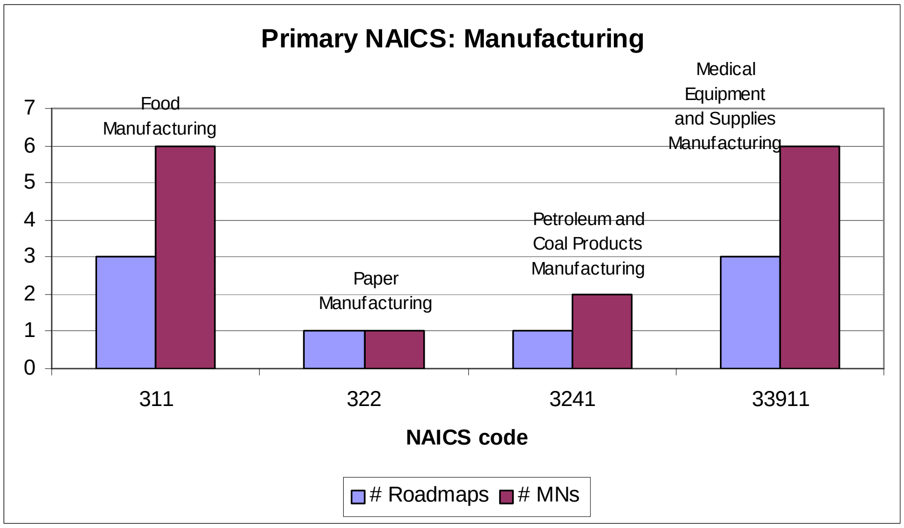

Figure 8. Selected Results for NAICS Manufacturing Sectors

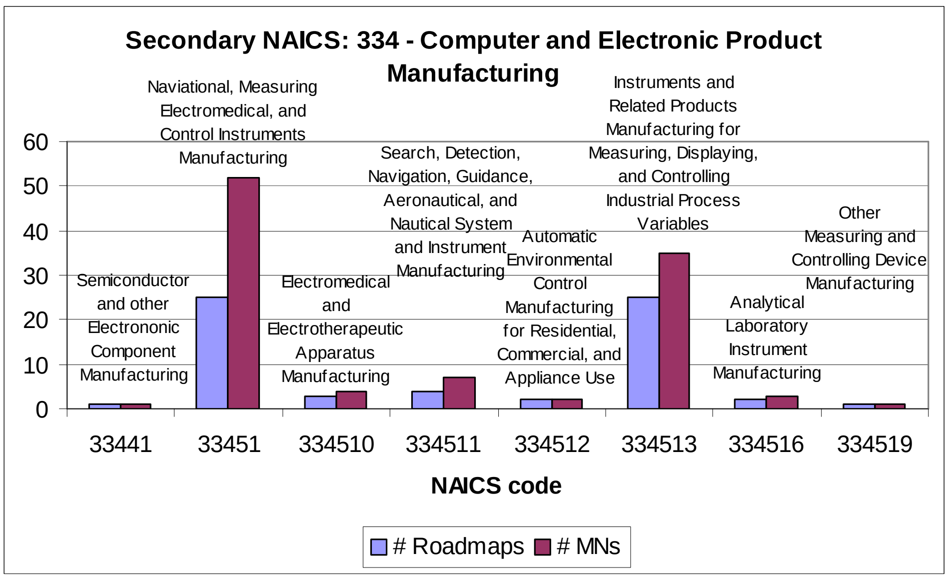

Figure 9. Results for NAICS Computers and Electronic Products

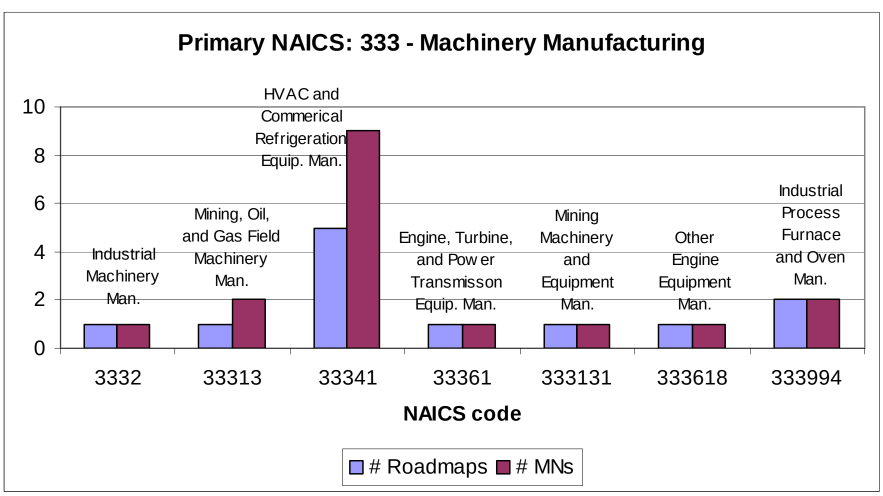

Figure 10. Results for NAICS Machinery Manufacturing

APPENDIX A: LIST OF TECHNOLOGY ROADMAPS AND REPORTS

RMNs	Roadmap/Report Title	Report Year
No	2004 Telecommunications Industry Playbook	2004
Yes	5th Annual CHP Roadmap Workshop	2004
No	A Climate Contingency Roadmap for the U.S. Electricity Sector: Phase II	2003
No	A National Benchmarking Analysis of Technology Business Incubator Performance and Practices	2003
No	A National Vision of America's Transition to a Hydrogen Economy	2002
Yes	A Roadmap for Web Services Adoption: A White Paper by netNumina Solutions	2003
Yes	A Science Roadmap for Agriculture	2001
No	A Strategic Plan for the Acquisition and Use of Information Technology for the City and County of Honolulu	2004
No	A Survey of the Use of Biotechnology in U.S. Industry	2003
Yes	A Technology Roadmap for the Generation IV Nuclear Energy Systems	2002
Yes	Accelerating Ionic Liquid Commercialization	2004
Yes	Advanced Ceramics Technology Roadmap	2000
Yes	Alumina Technology Roadmap	2001
Yes	Aluminum Industry Technology Roadmap	2003
No	American Association of Petroleum Geologists (AAPG) Strategic Plan	2004
Yes	An Integrated Roadmap for the Programmatic Resolution of Gas Generation Issues in Packages Containing Radioactive Waste/Materials	2001
Yes	Applications for Advanced Ceramics in Aluminum Production	2001
No	Arizona's Bioscience Roadmap	2004
Yes	Assessment Study on Sensors and Automation in the Industries of the Future	2004
Yes	Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002
Yes	BESAC Subcommittee Workshop Report on 20-Year Basic Energy Sciences Facilities Roadmap	2003
Yes	Biobased Products and Bioenergy Roadmap: Framework for a Vital New U.S. Industry	2001
Yes	Building Envelope Technology Roadmap	2001
Yes	Capital Projects Technology Roadmap	2004
Yes	Capturing the Full Power of Biomaterials for Military Medicine	2004
Yes	Carbon Sequestration Technology Roadmap and Program Plan - 2004	2004
Yes	Center for Advanced Separation Technologies Technology Roadmap	2003
Yes	Ceramic Coatings Metrology Workshop report	2000
Yes	Challenge and Opportunity on the Critical Path to New Medical Products	2004
Yes	Challenges in Information Retrieval and Language Modeling	2002
Yes	Chemical Industry R&D Roadmap for Nanomaterials By Design	2003
Yes	Clean Cities Roadmap	2004
Yes	Clean Coal Technology Roadmap	2004
Yes	Coatings on Glass Technology Roadmap Workshop	2000
Yes	Consensus Roadmap for Defeating Distributed Denial of Service Attacks: A Project of the Partnership for Critical Infrastructure Security Version 1.10	2000
Yes	Cyber Security	2005

RMNs	Roadmap/Report Title	Report Year
Yes	Data Storage Devices and Systems Roadmap	2005
No	Defense Display Strategy and Roadmaps	2002
Yes	Department of Transportation Strategic Plan 2003-2008: Safer, Simpler, Smarter Transportation Solutions	2003
No	Education Roadmap for Mining Professionals	2002
No	Electric Cooperative Technology Solutions	2002
Yes	Exploration and Mining Technologies Roadmap	2002
No	Exploring Our Future: Technical Communication in the Year 2013	2003
No	Final Report of the Commission on the Future of the United States Aerospace Industry	2002
Yes	Forging Industry Technology Roadmap	2002
No	Fostering the Bioeconomic Revolution in Biobased Products and Bioenergy	2001
Yes	Fourth Report on Needs in Ionizing Radiation Measurements and Standards	2004
Yes	Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2002 NAE Symposium on Frontiers of Engineering	2003
Yes	Fuel Cell Report to Congress (ESECS-1973)	2003
Yes	Fuel Cell Vehicles	2003
No	Fuel Cells for Buildings and Stationary Applications Roadmap Workshop	2002
Yes	Fundamental Physics in Space Roadmap	2003
Yes	Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation	2006
Yes	Getting Up to Speed	2004
Yes	Glass Industry Technology Roadmap	2002
No	Global Software Competitiveness... Numerically Speaking	2005
Yes	Grid 2030 - A National Vision For Electricity's Second 100 Years	2003
Yes	Heating, Ventilation, Air-Conditioning, and Refrigeration Technology Roadmap	2004
Yes	High Confidence Software and Systems Research Needs	2001
Yes	High Performance Commercial Buildings	2000
Yes	Hydrogen Posture Plan	2004
Yes	Industrial Combustion Technology Roadmap	2002
Yes	Innovation, Demand, and Investment in Telehealth	2004
Yes	Integrated National Plan for the Next Generation Air Transportation System	2004
Yes	International Micro-Nano Roadmap	2004
Yes	International OLED Technology Roadmap	2001
Yes	International Technology Roadmap for Semiconductors	2004
Yes	IST Roadmap for Optical Communications	2002
Yes	IT roadmap to a Geospatial Future	2003
No	Kansas Bioscience and Innovation Roadmap	2005
No	Maine Department for Professional and Financial Regulation (PFR) Strategic Plan	2002
No	Mapping the Future in Science-Intensive Industries: Lessons From the Pharmaceutical Industry	2005
Yes	Marine and Ocean Industry Technology Roadmap: Thinking Beyond Our Shoreline	2001
No	Market Opportunities in Space : The Near-Term Roadmap	2002
Yes	Materials Research to Meet 21st Century Defense Needs	2003
Yes	Measurement Needs for Fire Safety: Proceedings of an International	2000

RMNs	Roadmap/Report Title	Report Year
	Workshop	
Yes	Meeting the Energy Needs of Future Warriors	2004
Yes	Metal Casting Industry Technology Roadmap	2003
Yes	Micro-CHP Technologies Roadmap	2003
Yes	Mineral Processing Technology Roadmap	2000
Yes	Mining Crosscutting Technologies Roadmap	2000
Yes	Modeling & Simulation for Affordable Manufacturing	2003
Yes	Nanobiotechnology	2003
Yes	Nanoelectronics-Silicon and Beyond Workshop Report - Executive Summary	2003
Yes	Nanoscale Science and Engineering for Agriculture and Food Systems	2003
Yes	Nanoscience Research for Energy Needs	2004
Yes	Nanotechnology	2003
Yes	Nanotechnology and the Environment: Applications and Implications STAR Progress Review Workshop	2002
Yes	Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive Detection and Protection	2002
Yes	NASA Astrobiology Roadmap	2002
Yes	NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004
No	National Combined Heat and Power Roadmap	2001
Yes	National Hydrogen Energy Roadmap	2002
Yes	National Institute of Biomedical Imaging and Bioengineering DRAFT Strategic Plan	2005
No	NCSLI Strategic Roadmap for Metrology Education & Training	2005
No	New Biocatalysts	2002
Yes	New Directions in Manufacturing	2004
Yes	New Process Chemistry Technology Roadmap	2001
Yes	NIH Roadmap for Medical Research	2005
Yes	Oregon Department of Agriculture: Strategic Roadmap 2005	2005
Yes	Origins 2003: Roadmap for the Office of Space Science Origins Theme	2002
Yes	PM2 Industry Powder Metallurgy and Particulate Materials Vision and Technology Roadmap	2001
Yes	Quantum Computation Roadmap, Pt.1	2004
Yes	Quantum Cryptography Roadmap, Pt. 2	2004
Yes	Radio Frequency Identification	2005
Yes	Railroad and Locomotive Technology Roadmap	2002
Yes	Review of the Desalination and Water Purification Technology Roadmap	2004
Yes	Riding on Light - Optical Technology for Transportation Challenges	2003
Yes	Roadmap - Wisconsin Pulp and Paper Industry	2001
Yes	Roadmap for a National Wildland Fire Research and Development Program	2003
Yes	Roadmap for Biomass Technologies in the United States	2002
No	Roadmap for E-Government in the Developing World	2002
Yes	Roadmap for Process Equipment Materials Technology	2003
Yes	Roadmap for Process Heating Technology	2001
Yes	Roadmap to 2020 -- Defense Industrial Base Capabilities Study	2004
Yes	Science and Technology: A Foundation for Homeland Security	2005
Yes	Sensor Systems for Biological Agent Attacks	2005

RMNs	Roadmap/Report Title	Report Year
Yes	Software 2015: A National Strategy to Ensure US Security and Competitiveness	2005
Yes	Solar Electric Power: The U.S. Photovoltaic Industry Roadmap	2003
Yes	Solid State Energy Conversion Alliance (SECA) Workshop : 2001 conference proceedings	2001
No	Space Economic Data	2002
Yes	Status and Plans: The Fusion Simulation Project	2004
Yes	Steel Industry Technology Roadmap	2001
Yes	Strategic research directions in microgravity materials science	2004
No	Suborbital Reusable Launch Vehicles and Applicable Markets	2002
Yes	Technology Development for Army Unmanned Ground Vehicles	2002
Yes	Technology Foresight: Food Research Trends: 2003 and Beyond	2003
Yes	Technology Foresight: Industrial Wireless Technology for the 21st Century	2004
Yes	Technology Roadmap for Combinatorial Methods	2001
Yes	Technology Roadmap for Intelligent Buildings Technologies	2002
Yes	Technology Roadmap for Reaction Engineering	2001
Yes	Technology Roadmap for the 21st Century Truck Partnership	2000
Yes	Technology Roadmap for the Petroleum Industry	2000
Yes	Technology Roadmap for Thermally Activated Technologies	2003
Yes	Technology Roadmap: Buildings CHP	2000
Yes	The Chemical Industry R&D Roadmap for Nanomaterials By Design	2003
Yes	The Electricity Technology Roadmap Initiative	2003
Yes	The Food and Drug Administration's Strategic Action Plan Protecting and Advancing America's Health: Responding to New Challenges and Opportunities	2003
No	The Intel Lithography Roadmap	2002
Yes	The Lowell Database Research Self Assessment	2003
Yes	The Medical Imaging Technology Roadmap: An Overview	2004
Yes	The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004
Yes	The Science Ahead	2002
Yes	The State-of-Art and Future Trends in Testing Embedded Memories	2004
Yes	The Technology Roadmap: Energy Loss Reduction and Recovery in Industrial Energy Systems	2004
No	The UK Publishing Industry: Becoming the Public Face of Knowledge Engineering	2002
Yes	U.S. Aviation Science & Technology Roadmap - Volume 1: Aviation Vision	2000
Yes	U.S. Concrete Industry Technology Roadmap	2002
Yes	U.S. Photovoltaics Industry Roadmap	2004
Yes	U.S. Small Wind Turbine Industry Roadmap	2002
Yes	Unmanned Aerial Vehicles Roadmap	2002
Yes	Unmanned Aircraft Systems Roadmap 2005-2030	2005
Yes	Use of Lightweight Materials in 21st Century Army Trucks	2003
Yes	Vision 2020 Materials Technology Roadmap	2000
Yes	Vision 2020: 2000 Separations Roadmap	2000
Yes	Vision 2020: Lighting Technology Roadmap	2000
Yes	Vision 2030: A Vision for the U.S. Concrete Industry	2001
No	Vision for Bioenergy & Biobased Products in the United States	2002

RMNs	Roadmap/Report Title	Report Year
Yes	Welding Technology Roadmap	2000
No	What Businesses Need to Know About FDA's Plan to Combat Obesity	2005
Yes	Window Industry Technology Roadmap	2000
Yes	Workshop on the Roadmap for the Revitalization of High-End Computing	2003

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Measurement Needs have been abstracted from the Technology Roadmaps reviewed in this report and are summarized in the following pages.

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Final Report of the Commission on the Future of the United States Aerospace Industry	2002					
Fundamental Physics in Space Roadmap	2003	Improve instruments and existing experiments in the reduced gravity environment of space.	Precision measurements are proposed for space. This extreme environment will require adaptation of existing experiments and theories	Fundamental physical properties; atomic, physical and chemical properties of materials grown in space; phase changes and states of matter	Lasers cooling, gravitational physics, relativistic physics, low temperature and condensed matter physics, nano materials, ultra accurate clocks, microgravity	Fundamental physics measurements related to gravitational and relativistic physics, laser cooling and atomic physics, and low-temperature and condensed matter physics
Integrated National Plan for the Next Generation Air Transportation System	2004	Create a vast increase in the number and type of weather measurements made from ground-, satellite- and aircraft-based sensors.	N/A	Weather, atmospheric properties	Weather, sensors, aviation	Major improvements in weather sensor technology to increase safety and efficiency in the national aviation system
Integrated National Plan for the Next Generation Air Transportation System	2004	Harmonize approaches and compatible standards for U.S. and international airports for noise and local air/water quality issues. Achieve better understanding of the trade-offs between noise and emissions. Explore potential models and metrics to support the development of environmentally friendly air transportation.	N/A	Standards, sound, air, water	Noise level, air quality, water quality, aviation	Establish metrics and standards for noise, air quality and water quality related to aviation
Integrated National Plan for the Next Generation Air Transportation System	2004	Positively identify and rapidly screen air travelers and air cargo for threats. Identify and standardize requirements for security, public health, and identification of passengers and cargo. Detect and render man-portable air defense systems ineffective.	To automate detection and recognition of hazardous items, improved sensors are needed for man-portable air defense systems, chemical, radiological, biological and health conditions. Reliable, unobtrusive and accurate forms of identification are needed for passengers and cargo.	Chemical, radiological, biological, health, threat assessment	Security, chemical, radiological, biological, health, passengers, cargo, aviation, missile, MPADS, man-portable air defense systems	Techniques and standards for positively identifying threats to, or conveyed by, the air transportation system
Market Opportunities in Space : The Near-Term Roadmap	2002					
NASA Astrobiology Roadmap	2002	Achieve ability to determine the nature and fate of reduced gases that are produced by specific microbial ecosystems in an anoxic (pre-oxygenated) biosphere.	It is difficult to assess whether there is life on other planets through remote observations.	Biological	Astrobiology, NASA, space, life	Learn how to measure biosignatures that can reveal the existence of past or present life through remote observations. Carry out laboratory, observational and modeling studies to separate false from true biosignatures (e.g., atmospheric oxygen in a range of planetary environments).
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Review standards and metrics for particulate management; determine need/appropriateness for recommending modifications and characterize in situ airborne particulates/aggregates in microgravity habitat environment and particulate population distribution inside ventilation ducts; improve state of the art for monitoring particulate build up in closed-loop spacecraft systems.	The lack of a settling force has several consequences, none of which has been quantitatively investigated. Particulate matter measurement experiments will be conducted on board the International Space Station to better understand the particulate matter size distribution (below 10 microns) in a crewed spacecraft cabin.	Particulate distribution/aggregation	Particulate management, space exploration, microgravity, particle aggregation, particle distribution, standards	Quantify particle aggregation and size distribution in the absence of gravity driven settling; understand the effects of larger aggregates on deposition rates and how this can impact filtration devices
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	The development of new and novel fire detection and suppression systems would enhance the personnel safety in a space craft as well as safety of unmanned spacecraft, which depend upon a number of things like the detection and immediate suppression of fires.	Limited understanding of microgravity effects on detection, ventilation and sensor effectiveness as well as fire signatures	Fire signatures, particulate size, carbon dioxide levels, chemical constituents	Microgravity, fire detection and suppression, fire signatures, chemical elements, particulates	Understand fire signatures in microgravity

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	To support extended human space exploration missions, establish microgravity-compliant monitoring and control systems to support improved efficiency and reliability of spacecraft systems .	Current solid waste management systems perform only limited waste processing functions and are somewhat insensitive to microgravity conditions.	Moisture content	Solid waste management, space exploration, microgravity, control systems	Solid waste monitoring and control systems for use in microgravity environments
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Improved efficiency and reliability of spacecraft systems to support extended human space exploration missions	N/A	Particulate distribution/aggregation	Particulate management, space exploration, microgravity, particle aggregation, particle distribution	Measure and model: deposition, redispersion, entrainment and population changes of representative microgravity airborne particulates in controlled flows near boundaries and through grids or other large-opening arrays; diffusion-driven aggregation of airborne fine particulates in microgravity under controlled flow conditions; physical properties and deagglomeration/redispersion behavior of microgravity-representative "dust beds" consolidated under various airflow conditions
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Experimental characterization of multiphase flow systems under reduced microgravity, or appropriately scaled conditions in ground-based facilities will be essential for the development of life support system performance models and eventual validation.	N/A	Phase change, multiphase flow	Multiphase flow, phase change, accumulators, porous media, splitting/combining components	Understanding of flow through splitting/combining components (e.g., tees) through porous media, and into and out of accumulators
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Understanding stability dynamics as described is critical for many multiphase flow systems, which are considered mission-enabling for power, propulsion, and closed-loop advance life support systems capable of long duration flights. System designers must be able to accurately predict the basic behavior of these systems through a combination of two-fluid models, empirical correlations, and experimental reduced gravity data.	Currently, loop heat pipes and capillary pumped loop wicks are not designed from a first principles approach because the boiling limit at the wick's liquid/vapor evaporator interface is not sufficiently understood.	Stability dynamics	Stability dynamics, capillary surfaces, two-phase devices	Understanding of the stability dynamics of disconnected capillary surfaces is needed in many capillary-driven two-phase devices such as heat pipes, capillary pumped loops, wicks, and axial grooves or vanes
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Thermal subsystems are critical in several areas of advanced human support technologies for long duration microgravity and planetary missions. This includes cabin temperature and humidity control, space suit thermal and humidity regulation, two-phase and single-phase energy conversion/power-cycles, refrigeration systems, thermal storage systems, and normal and cryogenic fluid storage tanks.	N/A	Thermodynamics	Microgravity, thermodynamics, computational fluid dynamics, two-phase flow, phase distribution, phase transition	Develop empirical correlations, theoretical models, scaling laws and comprehensive computational fluid dynamics codes for two-phase flow in complicated geometries; boiling and condensation heat transfer; and phase distribution and phase transition phenomena in microgravity.

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Predictive capabilities of phase change and multiphase flow as described is critical for many systems, which are considered mission-enabling for power, propulsion, and closed-loop advance life support systems capable of long duration flights. System designers must be able to accurately predict the basic behavior of these systems through a combination of two-fluid models, empirical correlations, and experimental reduced gravity data.		Phase change, multiphase flow	Phase change, multiphase flow, predictive capabilities, microgravity	Predictive capabilities of phase change and multiphase flow in microgravity conditions, both computational and analytical, need to be developed to extend relatively small scale experimental results to practical full-scale systems.
NASA's Microgravity Fluid Physics Strategic Research Roadmap	2004	Predictive capabilities of the proper contact angle as described is critical for many systems which are considered mission-enabling for power, propulsion, and closed-loop advance life support systems capable of long duration flights. System designers must be able to accurately predict the basic behavior of these systems through a combination of two-fluid models, empirical correlations, and experimental reduced gravity data.	N/A	Fluid stability	Fluid stability, predictive capabilities, microgravity, contact angle	Techniques to predict the proper contact angle at the free surface/solid junction (when the contact line location is not fixed) and to assess this uncertainty on fluid stability in microgravity conditions
Origins 2003: Roadmap for the Office of Space Science Origins Theme	2002	Accurate knowledge of stellar positions within our own galaxy will allow us to calibrate luminosities of important stars and cosmological distance indicators, and improve our understanding of stellar processes.	Microdynamic disturbances	Distance	Space, stellar processes	The ability to measure precise distances throughout the universe (measure stellar positions throughout the universe)
Space Economic Data	2002					
Strategic research directions in microgravity materials science	2004	Perform environment monitoring utilizing lab-on-a-chip applications development (LOCAD) technologies.	N/A	Waste	LOCAD, waste monitoring	Waste monitoring and control
Strategic research directions in microgravity materials science	2004	Environment monitoring utilizing lab-on-a-chip applications development (LOCAD) technologies	N/A	Atmospheric conditions	Habitat monitoring, LOCAD	Habitat monitoring
Strategic research directions in microgravity materials science	2004	Ground based accelerator cross-section measurements	N/A	Radiation	Accelerator, nuclear, space radiation	Nuclear cross section measurements for simulation and validation purposes
Strategic research directions in microgravity materials science	2004	Safely extend the duration of crew deployment and lifetime radiation exposure. Enable deep space missions by safeguarding the crew against expected exposure.	Uncertainties exist in current understanding of interactions of space radiation with spacecraft materials	Radiation	Shielding, space radiation, deep space	Simulation and characterization of shielding effectiveness; radiation transport codes development; accurately determine the interactions of space radiation with spacecraft materials
Suborbital Reusable Launch Vehicles and Applicable Markets	2002					
U.S. Aviation Science & Technology Roadmap - Volume 1: Aviation Vision	2000	New standards will help reduce the environmental impact of aircraft operations in the United States.	Insufficient noise and emissions standards for new and modified airframe and engine designs	Noise, emissions	Aircraft standards, emissions, noise pollution	Develop noise and emission standards for certification of new and modified airframe and engine designs to mitigate the environmental impact of aircraft operations.

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
U.S. Aviation Science & Technology Roadmap - Volume 1: Aviation Vision	2000	High-tech sensor systems will provide the signals, images, and target/threat information needed to build an interactive common battlespace picture, providing comprehensive, accurate, and timely situational awareness for the warfighter.	Sufficient and inexpensive sensor systems need to provide the signals, images, and target/threat information required by warfighters. Current sensors used by the Navy/Marine Corps are larger and heavier than required for the functionality, and are not compatible with non military systems.	Radar, electro-optical systems, electronic support measures and countermeasures, navigation aids, automatic target recognition, sensor data fusion, antisubwarfare sensors and signal processing techniques for H2O, threat assessment	Sensors, reconnaissance, surveillance, military engagement, radar, electro-optical systems, navigation	Improved sensors: develop affordable air and space sensors that are networked to the warfighter and assure a complete and timely picture of the battlespace for precision engagement and survivability; develop avionics and sensor systems that are lighter, smaller, and have a greater degree of component commonality with other (especially commercial) systems
A Science Roadmap for Agriculture	2001	New epidemiological detection and tracking technologies such as microbial "fingerprinting" would help track the sources of microbial contamination and investigate food-borne illness outbreaks. Ability to identify and fully characterize known and as-yet-unknown food-borne pathogens will enable development of superior methods to detect and prevent the occurrence of pathogens and toxins in food.	Both diagnostic and the epidemiological investigation of food-borne pathogens and contaminants is impeded by a limited ability to rapidly pinpoint the source and/or cause existing and emerging food-borne illnesses. The growth of high-risk populations worldwide (e.g., infants and young children, AIDS patients, elderly, cancer patients, etc.) has made this a more critical dilemma now than in the past.	Frequency of health-related events, location and range, affected population characteristics, rate of spread, risk factors, prevalence, incidence, incidence rate, prevalence rate, rate difference, relative risk, pathogen identification and classification	Epidemiology, food, health, safety, microbial, contaminants, pathogen, bacteria, microbiology, toxin	Faster, more sensitive tests to detect food-borne illnesses
A Science Roadmap for Agriculture	2001	Develop biomarkers for nutrients and phytochemicals, and the ability to quantify the intake, adsorption, and effect of these substances in humans to aid the creation of healthier food by using conventional and molecular methods to modify food components.	Currently, the ability to quickly and easily determine the specific fatty acids in lipids in lacking, as well as determining the actual amino acids in proteins, the classes of carbohydrates that directly effect human metabolism, and the amount and the function of a full complement of minor ingredients.	Specific fatty acids in lipids, amino acids in proteins, carbohydrate classes, phytochemical content, probiotic content, constituent toxicity, biological	Food, health, nutrition, proteins, amino acids, lipids, fatty acids, carbohydrates, biomarker, probiotics, phytochemicals	Accurate measurement techniques to determine specific effects of various food constituents on human health
Kansas Bioscience and Innovation Roadmap	2005					
Oregon Department of Agriculture: Strategic Roadmap 2005	2005	Organize an automated, standardized animal tracking system using radio frequency identification tags, retinal scans, DNA, or other identification method.	Necessity to evaluate appropriate animal identification technologies for collecting animal movement data	Compatibility of identification method with animal species	National Animal Identification System, radio frequency tags, retinal scans, DNA	National Animal Identification System (NAIS): appropriate identification methods for an animal species

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
New Directions in Manufacturing	2004	Enable online, automated assessments and adjustment of system parameters.	N/A	Thermal, pressure, corrosion,	Sensors, harsh environment, manufacturing	Extend sensor reach and accuracy in harsh environments and improve the integration of processing of sensor data.
New Directions in Manufacturing	2004	Improve efficiency of electronic manufacturing services (EMS) and clear performance expectations. Eliminate duplicative or insufficient instructions	N/A	Standards	Standards, electronic manufacturing services, EMS, original equipment manufacturers, OEM, manufacturing	Standards for how original equipment manufacturers (OEM) program managers interact with electronic manufacturing services (EMS) suppliers
New Directions in Manufacturing	2004	Improve manufacturing performance.	Modeling and simulation technology		Modeling, manufacturing	Modeling capabilities that can be exploited by private companies with little initial investment in capital equipment
New Directions in Manufacturing	2004	Improve energy efficiency, reduce emissions, and enhance fuel flexibility.	N/A	Combustion, thermal, chemical, fuel, particulates	Energy efficiency, emissions, fuel flexibility, combustion, manufacturing	Understanding and control of the combustion process
Technology Roadmap for the 21st Century Truck Partnership	2000	Improved sensors for control systems will result in more efficient vehicles with reduced emissions. NOx and PM sensors with an adequate response time can aid in the control of engine-out emissions.	Lack of full electronic management (i.e., smart motors in place of belts and gears to drive accessories, flywheel starter motor/generator, etc.); a particulate matter (PM) sensor does not currently exist and NOx sensors are inadequate in the current configuration; lack of on-board diagnostics for energy storage devices (alternative power plants like fuel cells and gas turbines)	NOx, particulate matter (PM), engine temperature, pressure, coolant flow, airflow	Sensors, smart motors, control systems, emissions	Improved (accurate, reliable, real-time, robust) on-board sensors for (truck engine) process control and/or diagnostics
Technology Roadmap for the 21st Century Truck Partnership	2000	Improved methodologies for rapid aging and rapid screening of new catalysts will accelerate development of improved catalysts for reducing engine emissions.	Current methodologies for rapid aging and rapid screening tests are inadequate or unreliable.	Chemical, physical	Catalyst test methodologies, rapid aging, rapid screening, emissions	Test methodologies for rapid aging and rapid screening of new catalysts
Technology Roadmap for the 21st Century Truck Partnership	2000	Industry standards will enable the development and widespread use of technologies that address the issue of anti-idling at truck stops.	There is a lack of industry standards for electrical connectors and power level at truck stops and for heavy-duty vehicle electrical system designs.	Voltage, electrical connections, electrical system design	Industry standards, electrical power design, electrical power connections	Industry standards for uniform connector and power level for electrical power connections at truck stops, and electrical system designs (e.g., uniform voltage) for heavy-duty vehicles

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
A Survey of the Use of Biotechnology in U.S. Industry	2003					
Arizona's Bioscience Roadmap	2004					
Building Envelope Technology Roadmap	2001	A metric analysis product would enable consumers and designers to make more intelligent decisions and would serve as a powerful marketing tool for builders and building product manufacturers. It would also help streamline the assembly process and quality control mechanisms.	The overwhelming amount of information is difficult to process by consumers and builders without aid of a metric tool that can objectively and scientifically factor in all aspects important to decision making in building envelop design and purchase.	Energy efficiency; durability (resistance to wind, earthquakes, moisture, pests, etc.); affordability (monthly housing cost, life cycle cost, maintenance cost, first cost); adaptability; health (indoor air quality, acoustics, thermal comfort)	Building envelope, rating system, metric analysis tool, performance measurement, measurement system, performance monitoring, performance modeling	Absence of total system performance measurement for the building envelope: a simple, user-friendly rating system is needed to assess and communicate the performance of a building envelope and multiple attributes; a building modeling program that adequately predicts energy losses through roofs, basements, and foundations; diagnostic tools to measure and evaluate proper installation of various envelope components
Capital Projects Technology Roadmap	2004	The National Institute of Standards and Technology (NIST) is the most visible champion for R&D that supports this need and is working toward product data standards and integrated information systems to enable more efficient project planning. A major thrust in this area is the Construction Integration and Automation Technology (CONSIAT) program, which is aimed at significantly reducing cycle time and life-cycle cost through integration and automation of project information.	Complexity, data unavailable, requirements not fully expressed, reliance on tacit knowledge	Standards	Capital projects, standards	Industry standards to improve management of the planning stages of capital projects
Capital Projects Technology Roadmap	2004	Universal and open communication standards are needed to enable industry-wide interoperability and improved efficiencies. Both technical and financial parameters must be harmonized in new ways to facilitate the sustainability of lowest lifec-ycle costs.	Changes in the market, regulations, liabilities, and new requirements in response to homeland security needs add to the complexity owner/operators face in assessing requirements for facility maintenance, modification, and other life-cycle actions. The information required to accurately assess the current landscape is often missing, inaccurate, and difficult to translate to useful forms. Owner/operators have a wealth of data, but no protocols for interoperability to support integrated decision making.	Physical, life cycle, material properties, protocols, interoperability, homeland security	Capital projects, communication standards, facility management	Needs exist for facility assessment tools, facility performance modeling capabilities, capture and management of lifecycle data, and predictive maintenance to develop a deeper understanding of the physics of a given facility (material properties, process dynamics, etc.) to enable accurate interpretation of sensor data by both monitoring systems and human overseers.
Capital Projects Technology Roadmap	2004	Develop lightweight, high-strength, high-modulus materials and fabrication methods that enable low-cost assembly, maintenance, and ownership. Develop manufacturing and on-site assembly methods for lightweight materials.	N/A	Physical, materials properties, failure modes	Capital projects, specialized materials	Develop understanding of long-term life and failure modes and mechanisms of high-modulus materials and material systems such as woven fibers, textured materials, and their anisotropic behavior characteristics.

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Heating, Ventilation, Air-Conditioning, and Refrigeration Technology Roadmap	2004	Miniature wireless HVAC and indoor air quality smart sensors for fault detection and diagnostics, automatic and continuous commissioning, and monitoring and fine tuning HVAC and building performance; sensors use measured data, design data, and equipment operating parameters to diagnose system problems	N/A	Air quality, temperature	Indoor air quality, sensors, HVAC	Ability to detect faults in HVAC systems and quantify indoor air quality
Heating, Ventilation, Air-Conditioning, and Refrigeration Technology Roadmap	2004	Modeling tools provide manufactures with more accurate tools for developing residential systems with enhanced performance at high ambient temperature conditions.	N/A	Temperature, heat transfer	Heat exchange, air conditioning, high ambient temperature	Modeling tools that assist in the design of heat exchangers and air conditioning systems
High Performance Commercial Buildings	2000	Measurable, defensible, and reproducible financial returns and performance metrics will help create markets for commercial whole buildings (smart buildings).	Lack of performance metrics (e.g., energy and resource efficiency) for high-performance commercial buildings	Energy efficiency, resource efficiency, operational cost savings, asset value, productivity of tenant businesses, sustainable community development	Smart buildings, commercial building technologies, life cycle costs	Develop clear performance metrics (e.g., life cycle costs) that make a compelling economic case for and help define high-performance commercial buildings.
High Performance Commercial Buildings	2000	Smart, integrated building controls will enable optimized interactions among heating, lighting, daylighting, ventilation, and cooling subsystems, reducing consumption of energy and natural resources.	Lack of standard protocols for interoperability, difficulty and expense in retrofitting existing buildings, restrictive building codes	Standards, protocols	HVAC, building technologies, smart controls	Development of smart, cost-effective, integrated building controls, including sensors and wireless control technologies
Technology Roadmap for Intelligent Buildings Technologies	2002	The innovation is in the application of sensors and transducers on a "smart building."	Sensors and transducers are available and can make the required measurements. The real need is for an integrated communications system.	Strains, moisture, snow falls, temperature, current flow in conductors, vibrations	Concrete, cement, construction, materials, sensors, transducers, smart buildings	Need an integrated building monitoring system that can assess the condition of a building at all times, provide diagnostics, and self adjustments
Technology Roadmap for Thermally Activated Technologies	2003	Thermally activated technologies (e.g., advanced absorption, small air-cooled absorption chillers, ammonia-water heat pumps, triple effect absorption) that rely on waste heat recovery to produce both heat and power offer an innovative approach to heating, cooling and refrigeration in buildings. However, management of indoor air quality and moisture (humidity) will be critical for implementation of next generation thermally activated systems. These will need to provide energy efficient ventilation, incumbent moisture control associated with fresh air load, and removal of mundane pathogens/contaminants. Efficient measurement and monitoring technology for these elements is essential. While such systems exist to some degree, they are inadequate for use with many thermally activated technologies and new technology is needed that can	Current sensor technology for CO, H_2O, CO_2, and O_3 are too slow, and not sensitive or selective enough and cannot broadly demonstrate the IEQ value proposition. The link between humidity control, IEQ, and health/productivity is complex and crosses many disciplines (building science/engineering, architecture, chemistry, human physiology, microbiology, pathology, etc.). These groups do not have forums for regular interaction.	Chemical constituents in air (H_2O, CO, CO_2, O_3, volatile organics), enthalpy, air quality	Sensors, heat recovery, energy recovery, waste heat, indoor environmental quality, air quality, humidity control, buildings, district energy, HVAC, absorption, heat pumps, CHP	Advance measurement systems for humidity and indoor environmental quality (IEQ) in commercial buildings to enable the use of innovative heating, cooling and refrigeration technology. Develop high sensitivity, rapid response, broad-spectrum, low-cost, real-time air quality sensors for humidity and IEQ control. Sensors should measure and detect rising contaminant levels. Capabilities include measurement of enthalpy, CO, CO_2, and functional volatile organics with sufficient accuracy to make ventilation decisions in real time and be self-calibrating.

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Technology Roadmap: Buildings CHP	2000	Performance and cost savings metrics will provide BCHP industry players with data to help convince building owners, operators, and construction companies to incorporate BCHP systems into existing and new building, respectively. This will lead to more widespread adoption of BCHP systems and reduced energy use in buildings.	Lack of metrics for measuring the performance and cost savings of BCHP systems	Heat recovery component performance, utility rate structures, maps of thermal versus electric loads, source energy comparisons	Building technologies, HVAC, indoor air quality, CHP	Metrics supporting BCHP system performance: develop benchmark studies to establish metrics to characterize heat recovery component performance, utility rate structures, map thermal versus electric loads, and conduct source energy comparisons; define and develop standardized manufacturing data for HVAC equipment
Technology Roadmap: Buildings CHP	2000	Sophisticated, real-time monitoring and diagnostic tools and intelligent control systems will enable automated operations and remote diagnostics.	Lack of monitoring, diagnostics, and intelligent control tools/systems for BCHP systems	Temperature, humidity, fuel consumption, energy efficiency, emissions, indoor air quality, reliability impacts, profitability/value	Building technologies, HVAC, CHP, control systems, artificial intelligence, automated operation, remote diagnostics	More sophisticated monitoring and diagnostics for BCHP systems, in addition to intelligent control systems for automated operations and remote diagnostics
Technology Roadmap: Buildings CHP	2000	Standardization will enable the development of plug and play BCHP systems with modular designs to mix and match systems and subsystems, resulting in easy incorporation of BCHP systems into existing or new buildings.	Lack of standardized components and requirements for BCHP systems and subsystems	Standards	Building technologies, CHP	Develop definitions, standards, and specifications by building type, equipment type, climate zone, and building function for BCHP systems.
Vision 2020: Lighting Technology Roadmap	2000	High-quality lighting can measurably contribute to workplace productivity. More sophisticated lighting control technologies that are integrated into building design and allow end-user control will maximize the productivity benefits of better lighting while optimizing lighting/heat and energy consumption.	Currently, there is a lack of sophisticated, user-friendly lighting control technologies and systems.	Color, room temperature, occupancy of room, time of day, daylight levels, protocols	Building technologies, lighting controls, integrated control systems	Develop lighting controls with high levels of intelligence, interface capabilities, multiple levels of control, and ease of configuration. Controls would be easily installed (self-configuring, friendly to non-experts), self-teaching, intuitive, and have universal control and communication protocols for component interconnection (such as BACnet or Echelon).
Vision 2020: Lighting Technology Roadmap	2000	Development of industry standards and metrics will enable clear comparisons between different lighting products and technologies, and help the lighting industry provide a case for new and improved products.	Lack of industry-accepted standards and metrics for evaluating the quality and performance of lighting products and technologies	Lighting intensity, energy consumption, energy efficiency, standards, metrics	Lighting products, lighting systems, energy efficiency, industry standards	Develop metrics for evaluating the quality and performance of lighting products and technologies. Create industry-standard formats for energy and economics data for use across the many available software packages.
Window Industry Technology Roadmap	2000	Advanced window systems will offer many and varied properties and services in the future. Methods and standards for quantifying value and performance of the window systems will enable clear communication of the systems' benefits to consumers, growing the market for advanced window systems.	Lack of methods and standards for quantifying the value and performance of new window systems; ambiguous definition of durability	Standards, daylighting rating, fenestration durability, gas retention, solar heat gain, U-factor for sloped skylights, cost, life cycle benefits,	Windows, buildings, integrated building systems, energy efficient windows, commercial buildings	Methods for measuring performance and value of advanced windows: define performance metrics for comfort, system integration, energy, cost, and environmental impacts; develop methods for measuring the value of integrated systems; develop methods to measure and prove durability of fenestration products; establish a system for rating products on the basis of durability
Window Industry Technology Roadmap	2000	Standardized components and interfaces will allow for easier incorporation and integration of high performance window systems into new and existing buildings, creating a broader audience for the window systems. Integrated building systems can reduce energy consumption while enhancing comfort, lighting, security, and aesthetics.	Lack of integration tools and forms to achieve true system integration	Interface standards	Buildings, windows, integrated systems, sustainable buildings, commercial buildings	Define interface standards and protocols for integrating different building system components.
Advanced Ceramics Technology Roadmap	2000	Reduce manufacturing cost, thereby increasing competitiveness of advanced ceramics against other materials.	There is a lack of suitable sensor and automation technologies to increase process control and automation, and production costs of advanced ceramics need to be reduced to make them cost-competitive.	process variables	Sensors, controls, automation, semiautomation, production cost, materials manufacturing	Improved sensor technology for increased process control and automation in advanced ceramics fabrication and coating processes

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Advanced Ceramics Technology Roadmap	2000	Improved standards will enable consistent measurements across the ceramic composites industry.	Lack of testing procedures and standards for use in the development and life prediction of ceramic matrix composites.	Standards	Standards, testing procedures, material properties, life prediction	Test Standards in Support of CMC properties, including CMC life: develop screening parameters and uniform test procedures for rapidly assessing new ceramic matrix composite materials. Develop material and test standards for predicting life of ceramic matrix composites.
Advanced Ceramics Technology Roadmap	2000	Improved NDE methods will enchance product quality assurance and enable in-line, continuous, and rapid process control, helping to reduce fabrication costs.	Current NDE methods are slow, expensive, and labor-intensive and not applicable for in-line, continuous use.	Voids, density variations of composites	Nondestructive examination, NDE, quality assurance, reliability	Improved NDE (non-destructive examination) techniques need to be faster, cheaper, and able to be used in-line for continuous and rapid process control in the fabrication process and post-process.
Ceramic Coatings Metrology Workshop report	2000	Innovations in tests and tools for measuring coating properties will aid in increasing reproducibility and predictability of ceramic coating systems, helping to improve the performance, value, and competitiveness of products with ceramic coatings.	Lack of suitable methods for measuring ceramic coating properties; adhesion (most important); thermal conductivity; and wear resistance, for use in developing coatings and controlling product manufacture.	Thermal conductivity and diffusivity, microstructure, hardness, electrical resistivity, dielectric properties and breakdown voltage, stoichiometry, coefficient of thermal expansion, thickness, elastic modulus, interfacial strength and toughness	Coating properties, adhesion, reproducibility,	Methods and tools for measuring ceramic coating characteristics and properties, such as adhesion, thermal conductivity, and wear resistance to help coating designers and manufacturers improve coating system integrity.
Ceramic Coatings Metrology Workshop report	2000	Common standards and specifications for materials, processes, and applications will reduce the manufacture of low-quality product. In-line inspection methods can help reduce manufacturing costs.	Standards and specifications for materials, processes, and applications are lacking. Inspection methods are also lacking.	Standards	Thermal spray ceramic coatings, standards, inspection methods, nondestructive inspection, manufacturing	Standards and specifications for materials, processes, and applications; inline inspection methods
Accelerating Ionic Liquid Commercialization	2004	Property measurement and prediction is essential both for guiding synthesis and for developing applications. Research is needed toward a fundamental understanding of ionic liquids and should focus on industrial application-based problem solving aimed at production of low-cost ionic liquids with extended lifetimes, high contamination tolerability, and low toxicity for use in industrial applications. Universal access to the chemical, physical and thermodynamic properties of ionic liquids is needed to accelerate development and use of the same.	Currently unable to prove that ionic fluids can be economically and safely manufactured and used in diverse chemical processes.	Physical, chemical	Ionic liquids, physical and chemical properties	Numerous physical and chemical property measurements are required for the synthesis, characterization and use of ionic liquids. These include: vapor-liquid equilibrium and liquid-liquid equilibrium in water and other solvents, conductivity, interfacial tension, thermal properties, diffusion coefficients, stability at elevated temperature and in multiphase environments, refractive index, density, viscosity, and others.

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Accelerating Ionic Liquid Commercialization	2004	Modeling and characterization tools to aid synthesis will measure the technical performance and economic feasibility of industrial ionic liquid processes and new equipment designs. The technical and economic feasibility models will identify which ionic liquid applications potentially have commercial merit and this information will provide direction to researchers working on synthesis and property characterization.	Lifetime and recyclability data for ionic liquids is crucial to evaluating their viability in commercial applications. Ionic liquids may be sensitive to contaminants and may require frequent rejuvenation or replacement. The degree of sensitivity to impurities and the rate of degradation will have a large impact on ionic liquid functionality in industrial processes. Process engineering studies are required to obtain sufficient data on ionic liquid stability under long-term exposure to process conditions and exposure to air, moisture, heat, corrosion products, trace impurities (e.g., SOx, NOx, etc.) and other key industrial application components. Operational lifetimes have not been determined and these could impact the demand for and availability of ionic liquids. Ionic liquids that are too sensitive to contaminants or degrade under operating conditions may not be able to perform to the standards needed by industry.	Physical, chemical	Ionic liquids, physical and chemical properties	Develop modeling and characterization tools to aid synthesis of ionic liquids.
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	Accessibility to new tools will lead to technologically innovative approaches to nanomaterials design and use. Encouraging novel approaches, such as combinatorial materials characterization and "lab-on-a-chip" designs, will be key to innovations in the field of nanotechnology.	Capital and technical requirements for developing needed analytical tools are high and will require cooperation among industry, academia and government. Conducting proprietary R&D for direct-cost reimbursement at National User Facilities is prohibitively expensive for some researchers, and at some facilities, instrument scientists are forbidden to handle proprietary data.	Physical size/distribution, chemical composition, material properties, electronic properties, optical properties, electronic/magnetic properties, structure	Infrastructure, characterization tools, tool development, tool manufacturing	Infrastructure for supporting nanoscale characterization tool development and manufacture: affordable access to specialized government tools and facilities; partnerships to ensure the development of high-end next-generation analytical tools; foster commercial development of affordable robust analytical tools; develop effective and accessible data acquisition and management strategies and tools
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	Reference standards, standardized methods for synthesis and analysis protocols, and effective information management are vital to fostering technological innovation through nanoscience. These tools are necessary to accelerate the pace of discovery as well as commercialization. Researchers must be able to quickly convey scientific discoveries across disciplines, and consumers must be able to compare material attributes for technologic innovations to successfully enter the marketplace.	Reproducible, standardized methods for synthesis of nanomaterials are lacking; reference materials are needed to calibrate new measurement tools unique to nanomaterials; property standards are needed to ensure reliable performance of new analytical tools in measuring nanoscale material properties; no well-defined standards exist for accessing models developed for nanotechnology processes; standards for nanomaterial characterization are non-existent; a generally accepted standard taxonomy and language to describe nanoscience does not exist and hinders clear communication	Physical size and size distribution, chemical composition, material properties, electric properties, optical properties, electronic and magnetic properties	Standards, standard reference materials, SRMs, calibration, quality control, material properties, protocols	Develop standards for synthesis and analysis of nanomaterials, including: standard procedures for synthesis of nanomaterials; reference materials for property measurement standardization; standard methods for physical and chemical property evaluation; computational standards to improve information processing and transfer for modeling and simulation; standards for material evaluation in applications; internationally recognized nomenclature standards; and organizational infrastructure to foster standardization and development of standards.
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	Development and application of nanomaterials for innovative uses is currently hindered by an inability to produce these materials in a controlled and predictable way. Characterization tools to enable understanding of fundamental relationships between structure, properties and reactivity could significantly expand nanomaterial development. Accurate observation of phenomena at the nanoscale is a breakthrough technology that will enable innovative development and use of nanomaterials.	Properties of nanomaterials cannot be accurately predicted for all sizes, structure and compositions with current technology and knowledge; physics and chemistry of synthesis is not understood or characterized at the nanoscale; inefficient heuristic approaches are now used for synthesis; knowledge is limited between the "design" of nanostructures and the leap to device fabrication	Thermodynamics, kinetics, structure, structure-property relationships, defects, surface structure, composition, stability, size, purity	Nanomaterial, nanotechnology, nanostructures, assembly, self-assembly, synthesis, building blocks	Metrology to support synthesis of nanoscale materials: characterization, measurement and simulation probes that resolve all critical properties at the nanoscale; new nanoscale characterization tools to experimentally validate nanoscale properties; kinetic and thermodynamic principles guiding synthesis and assembly; database of key nanomaterial properties to compare performance to bulk properties; tools and processes to characterize nanostructure and nanoscale properties and to correlate macro to nano properties as a function of the synthetic approach; high throughput nanoscreening; protocols for evaluation of nanomaterials in applications that cross boundaries of synthesis, manufacture and use; peer-reviewed compendium of methods to synthesize and assemble nanomaterials

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	Nanomaterials are being manufactured with traditional, costly manufacturing techniques, which make them too expensive for many applications. Robust, reliable manufacturing methods would create a technology innovation that enables the use of nanomaterials in entirely new applications. Nanoscale manufacturing R&D and high-volume, cost-effective production will not be possible without advanced analytical tools.	Standardized measurement techniques do not exist; lab-scale techniques do not often translate well to manufacturing at larger scale; assembly techniques used in the lab do not necessarily scale-up to production scale	Dispersion, aggregation, kinetics, particle size and distribution, purity, composition, structure, physical properties, chemical reactivity	Nanomaterial, nanotechnology, nanostructures, nanoscale manufacturing, dispersion, self-assembly	Metrology to support manufacturing and processing of nanoscale materials: proven modular tools for integrated synthesis and assembly that could be used for mass production; techniques for direct measurement of dispersion characteristics and surface modification in a manufacturing environment; in-line measurement techniques to provide reproducible control of properties
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	Without an understanding of the EH&S issues of nanomaterials, new products based on rapid technological advances in this field may never leave the laboratory, despite their other benefits and advantages. Acceptable EH&S protocols based on sound characterization science will support accelerated R&D and product development, incentivize manufacturers to fabricate with nanomaterials, and increase willingness of consumers to purchase these products.	In situ testing without biasing results is a tremendous challenge. Characterization is difficult because of the extremely fine size of nanomaterials.	Particle size, composition, degradation, toxicity, lifetime, reactivity	Environmental impacts, exposure, health and safety, EH&S, emissions, waste, nanomaterials, toxicity, nanoparticles, biological fate	Measure the environmental and health effects of nanomaterials: tools and protocols to characterize the environmental and health effects of using nanomaterials, and to detect nanomaterials in the environment and workplace, including long-term and life-cycle impacts; development of exposure protocols; accurate real-time monitoring of environmental nanomaterials; handling guidelines for operations involving nanomaterials
Chemical Industry R&D Roadmap for Nanomaterials By Design	2003	The ability to create nanomaterials-by-design is currently hindered by the lack of adequate characterization tools. The technology innovation is to move from static measurements of quenched samples to dynamic, real-time measurements at the nanoscale. Precise 3-D characterization tools with this capability are essential to the advancement of R&D in fundamentals, synthesis, manufacturing, and commercial production of nanomaterials. These tools are also key to the development of models and simulations for predicting the behavior and performance of nanomaterials.	Optical, spectroscopic, scattering and other methods are reaching the limits of detection and resolution or are inadequate over large volume samples. The use of proximity probes to measure other chemical/physical properties (magnetics, electrical) is limited by measurement tool technology or is not capable of the needed spatial resolution.	3-D visual, temporal, chemical/physical properties (all); structure-property relationships; bulk scale properties.	Characterization, spectroscopies, scattering, microscopies, nanoscale, nanomaterials, nanotechnology, nanostructures	Characterization tools for understanding nanoscale structure and function: real-time methods and instruments to provide chemical and physical properties and structural information with 1-nm or less spatial resolution (spectroscopies, scattering techniques/Fourier Space, microscopies/Real Space); integrate techniques into 2-D real-time multi-probe systems with improved sample handling, miniaturization capability, vibration isolation, operation in-vacuo, in vitro and in vivo; ultimately integrate single and multi-probes in to real-time 3D imaging tomography
New Biocatalysts	2002					

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
New Process Chemistry Technology Roadmap	2001	Radically new ways of making chemical products could promote industry competitiveness and growth, while reducing the impacts of chemical processes on the environment and the associated costs of pollution abatement and control. The technological innovation is replacing hazardous/toxic reaction media currently used in chemical reactions with media that are more benign or do not require as severe operating conditions (e.g., ionic liquids, aqueous systems, high pressure and critical CO2 melt systems, and plasmas). An understanding of the kinetics and thermodynamics, physical and chemical properties, and solubility properties of new reaction systems are needed for process design, development, scale-up, and commercialization.	Properties data does not currently exist for many of the systems of interest, and is costly to develop.	Chemistry and physics of surfaces, interfaces, particles, and bulk materials; interactions with other species, chemical and isotopic composition, morphology, electronic structure; energetics, kinetics, mechanisms of reactions, other relevant property	Chemicals, chemical processes, chemical reactions, reaction media, alternative media, catalysis, chemical properties, physical properties, surface chemistry, surface interactions, reaction, data, thermodynamics, kinetics	Measurements to support the use of new reaction media: determine the kinetics and thermodynamics of mass transport processes in alternative media such as supercritical media, plasmas (e.g., surfactant behavior, diffusion coefficients, viscosity, dissolution rates); develop physical and chemical properties data for new reaction systems; develop a solubility database for existing and new solvents
Roadmap for Process Equipment Materials Technology	2003	Design of materials for process equipment could be substantially improved by the availability of "smart" properties databases that contain standard, reliable, refereed data and tools. These databases would incorporate the knowledge of "masters" in the fields of material science, as well as new data that has been verified according to specific rules and guidelines. The result would be better safety margins, less oversized and unproductive capacity, and optimized technology performance. This is particularly applicable to the design of materials for use in severe environments (e.g., high temperature, pressure, corrosion) such as those found in chemicals and petroleum refining.	Continued use of obsolete, proprietary, non-peer-reviewed or partial data; different interpretations of data across languages and classes; multi-disciplinary requirements for data networks; uncertainty about validity, sensitivity and accuracy of data	Thermophysical, chemical, thermodynamic, kinetic, corrosion, wear and stress, coking, degradation, mechanical and physical, defect propagation	Chemicals, chemical processes, chemical reactions, properties data, materials performance, materials of construction	Knowledge management systems for process equipment materials: develop reliable, standardized materials properties databases for metals and non-metals to support new and improved materials models as well as smart systems that link material performance with properties
Roadmap for Process Equipment Materials Technology	2003	Measuring and predicting materials performance while in use is critical to the productive and safe operation of processing equipment in the chemicals industry. Many current techniques are intrusive, require equipment shutdown, or in some cases compromise the integrity of the equipment. The ability to measure and monitor materials degradation in situ in a non-invasive manner would be a significant technological innovation leading to optimized operations and maintenance practices.	Lack of technology for online, non-intrusive in situ evaluation of materials degradation; inadequate data for predicting alloy performance and degradation rates; no technology for rapid evaluation of non-metallics performance; no standard polymer formulations for testing/comparison of data; lack of empirical data to build models	Thermophysical, thermodynamic, kinetic, corrosion, wear and stress, metal loss, metals, non-metallics, polymers, metal dusting	Materials degradation, corrosion, NDE, non-destructive evaluation, fouling	Measurement technology for assessment and prediction of materials performance: online sensors for detection of high temperature metal loss due to fouling; technologies for non-intrusive evaluation of materials; fast, high-precision measurement of property changes in non-metals exposed to corrosive environments; see-through pipe and vessel imaging; evaluation of wall loss, cracking material degradation for primary pressure membranes, linings, coating and claddings; sensors for corrosion under insulation; measure and predict defect propagation; data to support models of corrosion behavior over time, for all materials (metals, polymers, reinforced composites, filled polymers, advanced ceramics)

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Technology Roadmap for Combinatorial Methods	2001	Standardized data and data collection methodologies will support the development of advanced computational and combinatorial methods, reducing the volume of experiments necessary for designing new compounds.	Lack of data, standardized data, and standards for instrumentation	Chemical, kinetics, thermodynamics, standards	Combinatorial chemistry, computational methods, modeling, chemical properties, physical properties, kinetics, thermodynamic properties	Develop repeatable experimental methodologies and protocols and standards for experimental data collection. Develop common terminologies and methodologies for interpreting data.
Technology Roadmap for Reaction Engineering	2001	Advanced reaction engineering has the potential for accelerating the development of new chemicals, materials, pharmaceuticals, and catalysts, as well as reducing development costs. Better reaction/catalyst screening tools and reactor characterization techniques will contribute to improved reaction engineering, thereby bringing more products to the market faster.	Lack of online rapid reaction/synthesis screening tools and measurement techniques that allow experimental model verification under projected operating conditions	Chemical properties, physical properties, mechanical properties, micro properties	Screening tools, sensors, controls, reaction engineering, chemical synthesis, reactor characterization, reactors	Develop better tools for characterizing reactors (lab, pilot, and plant scale), and for screening reactions that are simple, robust, cheap, operate in-line, are non-intrusive, precise, reliable, highly selective, rapid, and can handle high throughputs. Develop non-visual reaction tracking methods for extreme reactor conditions.
Technology Roadmap for Reaction Engineering	2001	Improved process models will incorporate fundamentals of chemistry, reaction kinetics, and transport processes while spanning all size scales. They will capture the complexity of real systems at fine scales, which is important for multiphase systems that are currently extremely difficult to scale up. More accurate fundamental data will lead to more accurate models, helping to reduce the cost of scaling up processes and bringing new products to the market.	Efficient collection of complete and accurate kinetic, physical, chemical, and transport properties is difficult.	Physical, chemical, kinetic, transport, reactor residence time, reactor properties	Physical properties, chemical properties, transport properties, kinetics, reaction modeling, reaction engineering	Measurements in support of reaction engineering: determine physical, chemical, kinetic, and transport properties of real and complex molecules (polymers, long-chain organic molecules, etc.). Obtain better characterization of lab-scale reactors for obtaining kinetic data.
The Chemical Industry R&D Roadmap for Nanomaterials By Design	2003					
Vision 2020: 2000 Separations Roadmap	2000	Improved separation methods could significantly reduce the energy, cost, and wastes associated with process separations across the chemicals, pharmaceutical, refining, and food process industries. An understanding of physical, chemical, and solubility properties of adsorbents, solvents, etc. used in separation and purification processes is necessary to advance the science of separations.	Lack of fundamental data for different separation systems, including adsorbents, crystallization, solvent extraction, separative reactors, bioseparations	Solubility, mass transfer, interfacial tension, equilibrium, hydrodynamics	Chemicals, pharmaceuticals, food processing, separations, purification, thermodynamic properties, kinetic properties, physical properties	Measurements to support the use of new separation processes: determine physical properties of different adsorbent geometries and process conditions; determine properties (e.g., solubility, UNIFAC interaction parameters) of different solute/solvent mixtures such as organic/aqueous, organic/mixed aqueous-organic, organic melt mixtures, and nonionic organic/organic; determine properties, performance, mass transfer, interfacial tension, equilibrium, and hydrodynamics of solvents for extraction; determine and validate thermodynamic/kinetic/physical data for key chemical reaction chains with respect to separative reactors and for biologically-derived chemicals
Vision 2020: 2000 Separations Roadmap	2000	Current distillation processes are highly inefficient. Improved sampling, analytical, and imaging techniques will help process developers optimize tower design and operation resulting in reduced energy and capital costs.	Lack of in situ sampling, analytical, and imaging techniques for determining phase mixing and flow distributions in distillation columns; insufficient understanding of phase formation, mixing, interface area formation, mass transfer, and other processes occurring in a distillation column	Phase mixing, flow distribution, interfacial properties, process variables	Separation, distillation, in situ measurements, solvent extraction, bioprocessing	Improved sensors, imaging, analytical tools: develop better in situ sampling, analytical, and imaging techniques to determine phase mixing and flow distributions on distillation trays and in packed beds; develop interfacial sensors for solvent extraction; develop sensors and analytical techniques that are robust for bioprocesses

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation	2006	Improved characterization of geomedia and a better understanding of the impact of the measurement uncertainties will enable geoengineers to develop better solutions to civil and environmental engineering problems.	Lack of adequate characterization data of geomedia makes it difficult to accurately define the problem which leads to difficulty in developing a solution.	subsurface characterization, time effects, biogeochemical processes, rock/soil stabilization	geoengineering, geomedia, geomedia characterization	Develop improved characterization technology, quantification of the uncertainties associated with characterization, and methods for assessing the impacts of data uncertainties (risk analysis). Improve our ability to "see through" Earth.
U.S. Concrete Industry Technology Roadmap	2002	Material and physical properties measurements and model predictions are needed to predict the performance of concrete in applications. This would enable innovations in the design of structures and use of reinforcing materials. There is also a need to advance the technologies of measurement and monitoring of existing concrete structures, particularly with respect to detecting corrosion rates and activity.	Inability to predict the performance of structural systems	Weight, stress, fatigue, durability, weather resistance, seismic resistance, strength, material composition, curing properties, mixture content	Concrete, cement, construction, materials, sensors, structural materials, corrosion	Measurements and models to predict performance in-service (corrosion, cracking, permeability, composition over time, self-desiccation); multi-scale modeling to connect microstructure with engineering properties. Embedded sensors and smart materials to predict, monitor and adjust concrete according to interaction of stresses and environmental factors. Potential approaches include half-cell measurement techniques; X-ray fluorescence spectroscopy (XRF) for analyzing concrete composition; and improved forensic analysis.
U.S. Concrete Industry Technology Roadmap	2002	Industry needs to quantify benefits of using alternative materials for energy reduction, waste reduction, and utilization. This will allow concrete to become more competitive as a construction material.	Lack of data and tests for comparing alternative or new structural reinforcement materials.	Weight, stress, fatigue, durability, weather resistance, seismic resistance, strength, material composition, curing properties, mixture content	Concrete, cement, construction, materials, sensors, structural materials, corrosion	Tools and data for quantifying benefits of using alternative materials; tests for alternative reinforcement materials; predictive models for exposed structures with >2" cover over black steel rebar and welded wire reinforcement; models for predicting the performance of zinc-coated, epoxy-coated, combination zinc-and epoxy-coated, and stainless steel reinforced concrete structures.
U.S. Concrete Industry Technology Roadmap	2002					
U.S. Concrete Industry Technology Roadmap	2002					
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U.S. Concrete Industry Technology Roadmap	2002					
Vision 2030: A Vision for the U.S. Concrete Industry	2001	Employ computer-integrated knowledge and sensing systems to produce lighter, customizable, high-performance concrete products cost-effectively.	Limited research to date, and a lack of technologies to develop life-cycle data, field tests, and advanced concrete materials	Weight, stress, fatigue, durability, weather resistance, seismic resistance, strength, material composition, curing properties, mixture content	Concrete manufacture, life cycle analysis, agile manufacturing, composite materials, concrete aggregate, performance database, cement manufacturing, structural materials, NDE	Non-destructive measurements, sensors, intelligent curing techniques, and other technology advances to continuously monitor property performance and product durability
Capturing the Full Power of Biomaterials for Military Medicine	2004	Improve understanding of the three-dimensional interactions of cells on materials; immune response to biomaterials; techniques for rapid prototyping, micropatterning, and manufacturing of devices.	A common problem exists in the choice of the best treatment technology. Doctors have difficulty obtaining independent and objective advice about how to select the best materials for a particular medical procedure.	biological, immune response, materials properties	Screening methods, treatment technology, military medicine	Develop screening methods for enabling biomaterials technologies

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Capturing the Full Power of Biomaterials for Military Medicine	2004	Field monitoring of soldiers' physiological status is a very desirable tool and could be used for such beneficial activities as: sustenance of physical and mental performance; prevention of such nonbattlefield injuries as heat stroke and hypothermia; and improvement of casualty management. Need to provide early remote assessment of the field soldier. If the forward medic could monitor the exact location of any soldier in his squad and the soldier's wearable sensors could measure heart rate, respiration, core and skin temperatures, blood pressure, cardiac output, fatigue, blood oxygen, total weight, and hydration, the overall effectiveness of the medic and the unit would be greatly improved. This goal could be accomplished using multifunctional, lightweight, off-the-skin, micromachine sensors that are integrated with the soldier's uniform or implanted.	Monitoring algorithms specific to military needs may not be available. Other technical hurdles include: developing a high-level system of diagnostic needs that will help to optimize sensor needs and facilitate the development of the most important combination of sensors; reducing sensor size and weight (perhaps through micro- and nanotechnology); building sensors that function in multiple environments and conditions; developing off the skin (e.g., wearable) or implanted sensors; and building sensors that have low signature to avoid detection by enemy forces.	Physiological	Physiological sensors, military medicine, monitoring algorithms	Develop physiological sensors and diagnostics for military use including necessary algorithms to interpret the sensed data. Sensors should measure heart rate, respiration, core and skin temperatures, blood pressure, cardiac output, fatigue, blood oxygen, total weight, and hydration. In addition, sensors should detect chemical and biological agents with early warning to provide ample time to employ protective biomaterials for the skin and biofilters to protect respiration. Sensors should also track identification and location.
Defense Display Strategy and Roadmaps	2002					
Materials Research to Meet 21st Century Defense Needs	2003	Develop ability to predict possible material properties and functionality before development costs are incurred and predict material properties and behavior so that the cost of characterization could be reduced. This would not only reduce costs but also accelerate material development, especially the introduction of new/composite materials and materials systems into DoD systems. Integrated sensors can better examine structures than outside sources.	Necessity of more precise understanding of physical phenomena and better computer equipment that can extract the important data from a calculation and also analyze first-level data to implement new/composite materials by integrating constitutive models into a framework that employs FEM calculations; lack of continuous health monitoring of new structures	Physical properties, performance, material behavior	Characterization, material properties, models, sensors	Metrology to support structural and multifunctional materials: materials design/models assisted by computation; integrate nondestructive inspection and evaluation into design
Materials Research to Meet 21st Century Defense Needs	2003	Understand potential effectiveness or limitations of a material in a class of applications and accelerated ability to introduce applications of novel materials.	Necessity to use material properties in a controlled and reliable manner, while assuring that the structures remain stable over extended use; considerably long period (>20 years) before the introduction of new energetic materials	Physical properties, chemical properties, performance, interface/surface reaction kinetics, nanomaterials	Characterization, material properties	Metrology to support energy and power materials: nanomaterial, interface/surface characterization; tools for accelerated systematic materials discovery and application
Materials Research to Meet 21st Century Defense Needs	2003	Fundamental scientific understanding is likely to give knowledge of the ultimate properties of a material and serve as a guide to understand, control, and optimize processing of existing, new, and combined materials.	Lack of models that span length scales from nanometers to the scale of the material/device; important properties of many materials that are promising for defense applications are not well understood, where an undiscovered intrinsic property of a material may ultimately make it wholly unsuitable for the application; lack of characterization of single-phase materials with more elements and crystallographic complexity than have historically been considered; lack of understanding of interaction at interfaces between materials, where the functionality often is derived from materials properties very close to the interface	Physical properties, chemical properties, performance, interface interaction, electronic, photonic	Characterization, material properties, models, nanomaterials	Metrology to support electronic and photonic materials: theory, modeling, and tools for material processing and fundamental understanding of existing materials, new materials with extreme properties, and combined materials

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Materials Research to Meet 21st Century Defense Needs	2003	Obtain ability to have optimized chemical and structure selection for specific functionalities, selected polymers with completely defined chemical structures, enhanced homogeneity, and purity.	Lack of high level modeling and simulation to determine critical parameters; current inability to match sometimes disparate properties like thermal expansion and optical absorption in hybrid materials; lack of sequence-controlled polymerization of a wide variety of polymers	Physical properties, chemical properties, performance, integration, polymerization characteristics	Characterization, material properties, models, simulations, semiconductors	Metrology to support functional and organic hybrid materials - computer modeling and simulation; convergence and integration of organic and silicon (and other semiconductor) electronics and photonics in hybrid architectures; new synthetic strategies to produce high yields of selected polymers
Materials Research to Meet 21st Century Defense Needs	2003	Many molecules, structures, systems, and natural fabrication processes have the potential to serve as the basis for materials with enhanced properties for defense applications, either directly adapted or as a pattern for nonbiological mimics.	Biological systems have clearly shown that large numbers of molecules, structures, and systems in living organisms possess attractive materials properties that are beyond the reach of current nonbiological synthetic approaches.	Biological properties/processes and how they can be applied to material synthesis	Biological properties, characterization, models, material properties, biotechnology	Metrology to support bioinspired and bioderived materials: models of biological molecules, structures, systems, and processes to lay the groundwork for use in serving material needs
Materials Research to Meet 21st Century Defense Needs	2003	Obtain understanding of organic materials providing robust defenses against laser threats to personnel and equipment; implantable, in vivo detection to identify toxins and pathogens, including masked agents, that may enable the detection of a single agent molecule; and embedded catalysts to act as both sensors and actuators to provide in situ defenses by neutralizing chemical and biological attacks.	Limited ability of current devices to provide complete protection against laser, chemical, and biological attack; necessity of new production methods and support structures	Optical nonlinearity and chemical and photochemical stability (lasers), biological compatibility, physical properties, chemical properties, performance	Chemical, biological, material properties, detection, defense, sensors, homeland security	Sensors, detection devices for personnel defense: laser threats, chemical and biological attack
Meeting the Energy Needs of Future Warriors	2004	N/A	Lack of detailed understandings of the dynamic characteristics of the power supply system and of the duty cycle	Energy efficiency	Portable energy supply, energy efficiency, military, energy storage	Standard measures to facilitate comparison of energy efficient technologies for the dismounted soldier
Meeting the Energy Needs of Future Warriors	2004	Full simulation of objective force warrior power sources and sinks would help to determine the directions that developments must take to have the most impact. Systems could then be designed using aggressive techniques tailored to each application and to the most likely soldier modes of interaction, thus reducing power requirements for computation and communication by several orders of magnitude.	Given a mission scenario, a suite of soldier equipment, and the size or makeup of a combat team, the Army should be able to determine an optimum type, quantity, and distribution of power sources, as well as fuel requirements. While developers must have scenarios against which to be measured, the diversity of missions given to dismounted soldiers virtually assures that large standard deviations will exist. Simulations of operations, along with real-world measurements, may narrow these modeling deviations, but there will always be a broad spectrum of operations to be considered.	Dynamic loads	Portable energy supply, dynamic loads, military, energy storage	Measurements of dynamic loads are needed to enable simulations of dynamic operation of land warrior electronics synchronized with a power source simulator. This measurement can be used to model the active, peak, and standby power of all the components, so that each power sink can be simulated.
Meeting the Energy Needs of Future Warriors	2004	Develop microelectromechanical system components for power technologies.	N/A	Electromechanical, electronic	Portable energy supply, microelectromechanical systems, MEMS, military	Establish performance metrics and cost analysis for microelectromechanical systems (MEMS) based components
Meeting the Energy Needs of Future Warriors	2004	The validated models should lead to more effective planning and designs. For example, the optimal suite of energy storage and energy conversion devices, fuel quantities, etc., could be determined for each mission.	Model materials properties through system integration; model steady-state and transient power source/sink behavior; establish control algorithms that optimize energy use	Energy sources and sinks, material properties	Portable energy supply, energy models, fuel cell, military, energy storage	Develop generic modeling capabilities of energy for electronics, weapons and power sources of land warriors. It should include models of competing energy sources, including fuel cell systems, and use in simulations of battlefield operations. In addition, models should incorporate soldier usage patterns and other details of interactions between power sources and soldier electronics.
Roadmap to 2020 -- Defense Industrial Base Capabilities Study	2004	Active magnetic signature reduction systems will be improved through advancements in real-time magnetic field measurement systems, which feed into active magnetic signature reduction systems.	May need to develop new sensor technology	magnetic field	magnetic field, active magnetic signature reduction, sensors	Advanced real-time magnetic field measurement systems

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Roadmap to 2020 -- Defense Industrial Base Capabilities Study	2004	The use of standard hardware and software interfaces is fundamental to ARCI's ability to continue innovation throughout the system life cycle. Standard hardware and software interfaces enable a maximum level of innovation for development and continued improvement of critical warfighter capabilities.	N/A	Standards	Acoustic Rapid Commercial off-the-shelf Insertion (ARCI), hardware standards, software standards, interfaces	Standards for hardware and software interfaces that support the Navy's Acoustic Rapid Commercial off-the-shelf Insertion (ARCI) program
Technology Development for Army Unmanned Ground Vehicles	2002	Improvements could yield optimized perception systems for unmanned vehicles and revolutionary defense systems for the future.	Improvements in individual sensor capabilities and algorithms are needed, but a big problem, largely unacknowledged, is optimizing the perception system hardware and software architecture: sensors, embedded processors, coded algorithms, and communications buses. There is currently no way to know how perception performance is reduced by sub optimized architecture or where improvements might be made.	Software assurance, hardware performance	Defense, unmanned vehicles	Metrology for optimizing perception technologies for autonomous mobility, including sensors, processors, and algorithms to measure performance
Unmanned Aerial Vehicles Roadmap	2002	Revolutionize sensing and detection technology to support unmanned aerial vehicles and new defense concepts.	Need improved sensors for detecting and identifying the target and improve aim point accuracy.	Light, radar,chemical, biological, radiological, meteorological, magnetic	Unmanned, automated, sensors, weapons	The dominant requirement for sensing is for imaging (visible, infrared, and radar), followed by signals (for the SIGINT and SEAD missions), chemical weapons of mass destruction (WMD, biological WMD, radiological WMD, meteorological (METOC), and magnetic ASW and Mines Counter Measure (MCM).
Unmanned Aircraft Systems Roadmap 2005-2030	2005	Enhance mission capabilities with an effective and highly autonomous system that can operate and handle aircraft-related and mission-related contingencies while unable to communicate with the mission control system due to self-jamming (interference with command and control communications by electronic attack emissions) and covert operations.	Without the development of autonomous electronic attack operating capability, the transmission of large amounts of data assessing the tactical environment must be provided to remote human operators in real-time. These large transmissions would be limited by available bandwidth and self-jamming and could increase the unmanned system's vulnerability. The trade-off between effectiveness and survivability also needs to be understood when considering the effective range of the UA in neutralization missions.	Effective range, tactical environment, threat assessment, sensors	Unmanned aircraft, strike/suppression of enemy air defense, electronic attack, effective range, autonomous system	Metrology to support the autonomy of unmanned aircraft (UA) systems in strike/suppression of enemy air defense/electronic attack missions: rapid detection of enemy defensive system operations; effective range; onboard intelligence; ability to recognize and respond to previously unknown threat defensive system modes, frequency, and tactics
Unmanned Aircraft Systems Roadmap 2005-2030	2005	Achieve combined sensor products for innovative, novel, and perhaps currently unanticipated ways to perform the more demanding mission facing Department of Defense (DoD) forces today, with data from UA sensors posted at the appropriate phases of processing to the Global Information Grid (GIG) to enable other users to take advantage of the collected product and not restrict them to only using the processed product. Also, employing a standardized system of commonality and compliance with data standards will maximize the return on investment that new generation sensors represent.	More demanding operational information needs, such as identifying an individual from standoff distances or detecting subtle, man-made environmental changes that indicate recent enemy activity, demand a higher level of performance than provided by the current generation of fielded UA sensors. It is a necessity to have data and relevant metadata in a common, published, accepted format, in compliance with DoD's Network Centric Data Strategy, in order to maximize the utility of the products from UA.	Light, nuclear, standards, SAR, illumination	Unmanned aircraft, sensors, imagery, detection, autonomy, compliance, standards, performance	Metrology to support sensor development: multispectral/hyperspectral imagery; characterization databases; Synthetic Aperture Radar (SAR) enhancements; UHF/VHF Foliage Penetration (FOPEN) SAR; Light Detection and Ranging (LIDAR) FOPEN; LIDAR imaging, illumination; Tactical Signals Intelligence (SIGINT); nuclear detection systems; optical performance improvement (HDTV); focal plane array and stabilization technologies; air vehicle/sensor autonomy/self cueing; standards
Unmanned Aircraft Systems Roadmap 2005-2030	2005	Develop interoperability and integration of UA systems with the Global Information Grid through appropriate standards and protocols, which would enable effective exchange of information as required for mission accomplishment.	UA systems muct be interoperable with DoD information networks and services.	Standards, interoperability	Unmanned aircraft systems, standards, reliability, interoperability, performance, material properties, internet, networks	Interoperability standards: networks, internet, internetworking, data, data links

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Unmanned Aircraft Systems Roadmap 2005-2030	2005	Lightweight structures and smart materials such as shape memory alloys offer alternatives to the servos, flight control surfaces, and de-icing systems of existing aircraft designs. They also reduce components count and increase reliability. Cold weather tolerance needs to be improved, as well as operation in precipitation and suboptimal wind conditions for enhanced UA reliability and availability in real world operations. Also, improve weight to strength/wear and increased efficiency with advanced materials for fuel systems and ancillary components. Increase wing performance through airfoil-shape change for multipoint optimization, and active aero elastic wing deformation control for aerodynamic efficiency and manage structural loads. Improve stability of small UA through expanded research in the area of Small Reynolds Number.	Current levels of reliability impact UA systems' operational utility, their acquisition costs, and their acceptance into airspace regulations. This creates the necessity to assess and enhance UA systems' ability to perform their intended functions for a specified time under stated conditions.	UA performance reliability, efficiency, material properties	Unmanned aircraft systems, reliability, performance, efficiency, material properties	Metrology to support UA reliability: flight operation, UA operation, advanced materials and structures, weather tolerance
Use of Lightweight Materials in 21st Century Army Trucks	2003	Insertion of lightweight, corrosion-resistant materials into military vehicles could radically improve fuel economy and maintenance of these vehicles in service.	Data needed to design components to meet specific performance requirements, e.g., fatigue life, is often unavailable for the specific material being evaluated. The lack of adequate databases needed for accurate finite element modeling (FEM) exacerbates the design community's existing lack of familiarity with lightweight materials. In addition, appropriate models for processing lightweight materials and for predicting the performance of components manufactured using these materials must be developed.	Mechanical, chemical	defense, military, databases, data, materials, trucks	Materials data (peformance, materials properties, etc) is needed to evaluate alternative materials for given truck applications and to optimize vehicle design. Data would support accurate finite element modeling as well as materials processing and performance prediction.
International Micro-Nano Roadmap	2004	Because there are very few existing microsystems standards, over the next decade as applications mature, standardization across all phases of microsystems manufacturing will be necessary for continued growth.	N/A	Standards	Microsystems, standards	Develop microsystem manufacturing standards.
International OLED Technology Roadmap	2001	Obtain device stability through the following: performance must not degrade markedly with age; appropriate voltage and current control; and active organic materials to produce fine patterns with vivid colors and superiority over present LCDs. Also, improve light extraction and reduce fabrication costs.	Ability to scale up the OLED displays to be competitive in size, reliability and cost with present and projected LCDs	System energy efficiency, system efficacy, RGB color saturation, lifetime, pixel density, contrast, max pixel number, display size, maximum voltage swings, panel weight, and fabrication costs	Organic materials, light emitting diodes, active matrix, passive matrix, small molecule materials, polymer materials, optical display characteristics	Continue to develop reliable, standardized state-of-the-art measurement tests of the optical and electrical properties of OLED displays based on the present measurement capability in LCDs.

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Review of the Desalination and Water Purification Technology Roadmap	2004	One potential solution to the nation's water supply problem is to utilize increasingly impaired waters, such as municipal wastewaters, by applying desalination treatment technologies for contaminant removal. While well-functioning membranes can be a robust barrier that can result in significant contaminant reduction, one should not presume complete removal. Sensitive detection technologies are important for contaminants that may cause acute or chronic adverse health effects at low concentrations. Additional research and development are needed to lower analytical detection limits for contaminants so that potential associations with observed health effects can be discerned. Similar concerns exist for analysis of viruses and protozoa in drinking water. The sensitivity of current log removal calculation methods is a function of both the volume of sample collected and the	Need to improve techniques for identification and quantification of chemical contaminants and more sensitive online membrane integrity monitoring systems.	Water contamination, chemical, biological	Wastewater treatment, desalination, water supply	More complete identification of the contaminants present in treated wastewaters and lower analytical detection limits for contaminants are needed so that potential associations with observed health effects can be discerned.
Review of the Desalination and Water Purification Technology Roadmap	2004	A tiny area of defects in the membrane surface of an otherwise perfect barrier to pathogens can allow a number of organisms to pass across the barrier into the product water. In cases involving long storage time, some non-parasitic organisms could multiply to an unsafe level of pathogens in the product water.	Molecular based biological markers for integrity monitoring	Membrane integrity	Water purification, desalination, membranes, sensors	Sensors to assess membrane integrity used in water purification / desalination plants
Review of the Desalination and Water Purification Technology Roadmap	2004	Improve the consistency and reliability of the quality of the product water.	N/A	Water contamination	Wastewater treatment, desalination, particulates	Ability to monitor wastewater particulates based on size and shape because newer technology that classifies particulates based on pattern recognition promises to provide early pathogen warning through online/real-time applications
Nanotechnology and the Environment: Applications and Implications STAR Progress Review Workshop	2002	Achieve efficient and rapid in situ biochemical detection of pollutants and specific pathogens in the environment; sensors capable of continuous measurement over large areas, including those connected to nanochips for real-time continuous monitoring; sensors that utilize lab-on-a-chip technology; and sensors that can be used in monitoring or process control to detect or minimize pollutants and their impact on the environment.	Increasing concern over environmental conditions and the health effects of fine and ultrafine particles requires more accurate, less costly, more sensitive techniques in order to enable major improvement in process control, compliance monitoring, and environmental decision making.	Chemical compositions, sensor accuracy, selectivity, and sensitivity	Nano, nanotechnology, sensors, detection, environment, pollutants, pathogens, toxins	Novel sensing technologies or devices for pollutant and microbial detection: ultrasensitive pathogen quantification in drinking water; chemosensors for marine toxins; nanostructured porous silicon and luminescent polysiloles as chemical sensors for carcinogen chromium (VI) and arsenic (V); nanocontact sensor for heavy metal ion detection; real-time chemical composition measurements of fine and ultrafine airborn particles; simultaneous environmental monitoring and purification
Nanotechnology and the Environment: Applications and Implications STAR Progress Review Workshop	2002	Develop suitable replacements for Pt-group metals for cost-effective automobile catalytic converters with reduced NO_x, CO, and HC emissions.	Current catalytic converters will not be able to meet future emissions reduction targets without increasing the amount of Pt-group precious metals to levels at which the converters might become prohibitively expensive.	Chemistry, structure, catalytic properties	Nanoparticles, catalysts, environment, emissions, nanomaterials	Characterization of nanoparticles of transition metal carbides and oxycarbides
Nanotechnology and the Environment: Applications and Implications STAR Progress Review Workshop	2002	Achieve the ability to produce dispersed suspensions of nanoparticles without absorbed additives by identifying what variables can be controlled to alter solvation or depletion forces.	A significant limitation of nanotechnology is the ability to produce bulk quantities of dispersed particles. One possibility for dispersing nanoparticles, which have a high area/mass ratio, is to use adsorbed polymer, oligomer, or surfactant molecules. However, disposal of the enormous quantity of additives would involve huge environmental and financial stresses.	Van der Waals, solvation, and depletion forces of nanoparticle systems	Nanoparticles, Van der Waals forces, solvation forces, depletion forces, dispersion, models, nanomaterials	Measuring and modeling nanoparticle forces

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Nanotechnology and the Environment: Applications and Implications STAR Progress Review Workshop	2002	Achieve facile adsorption and desorption, the ability to form dense films to facilitate separations applications, and optical transparency of zeolite nanostructures. Obtain effective NOx emission abatement, photocatalytic decomposition of organic contaminants, and environmentally benign selective oxidation reactions with cation-exchanged nanometer-sized zeolites.	Zeolites are widely used in separations and catalysis, but the crystal size formed during conventional synthesis ranges from 1,000 to 10,000 nm. It would be advantageous in some applications to use zeolite crystals in the range of 10 to 100 nm	Structure, effectiveness, catalytic properties	Nanostructures, catalysts, environment, emissions, nanomaterials	Characterize nanometer-sized zeolites and nanostructures (films, fibers); determine the effectiveness of utilizing nanometer-sized zeolites as environmental catalysts
A National Benchmarking Analysis of Technology Business Incubator Performance and Practices	2003					
Maine Department for Professional and Financial Regulation (PFR) Strategic Plan	2002					
Measurement Needs for Fire Safety: Proceedings of an International Workshop	2000	Improved tools, methods, and guidelines for measuring fire properties will enable the development of fire safety models based on consistent data.	The lack of adequate tools, methods, and guidelines for measuring fire properties leads to fire safety models based on data containing high uncertainties.	Heat flux to the surface of a burning sample, gas velocity over spatial areas in a room fire environment, temperature over areas in a room fire environment, heat release rate from full-scale burning objects, smoke characteristics	Fire safety, modeling, fire characteristics	Better tools, methods, and guidelines for measuring fire properties (e.g., temperature, spatial gas flow) to enable better fire safety models. Varying time responses of calorimeters in different labs affect the observed values of peak heat release rates.
Roadmap for a National Wildland Fire Research and Development Program	2003	Gains realized by exploiting scientific advances in measurement and other technologies would create safer, more effective firefighting procedures, improved fuels management techniques, and reduced loss of lives, property and natural resources.	In situ observations of fires are possible but need to be expanded and refined. Characterization and modeling of fuels is lacking for many fuel types across the United States and Alaska. The complexity of modeling systems for wildland fire fuel maps will be high, requiring integration of data on land cover, weather, terrain, vegetation type, moisture level, historic fire regimes, fuel breaks, and other characteristics.	Chemical composition, particulates, air pollutants, greenhouse gases, metals, nutrients, moisture, temperature, wind speed, fuel characteristics, combustion chemistry	Fire, wild fires, wildland fire, wildland fire science, fire dynamics, combustion chemistry, fuel chemistry, fire emissions, fire fuels, first responders	Measurement and imaging techniques are needed to better understand wildfire behavior, including fire/atmosphere dynamics, fuels assessment, fire emissions, and combustion chemistry and physics. Examples include enhanced visual imagery of fire spread coupled with remote sensing and numerical models; characterization of the wide variation in fuels, coupled with remote sensing; advanced methods for generating wildland fire fuel maps; and characterization of the composition of emissions released by burning biomass.
Technology Foresight: Food Research Trends: 2003 and Beyond	2003	Better understanding of food properties and nutrients could lead to technological innovations in food texture, packaging and formulation for maximum nutritional value.	N/A	Composition, chemistry, chemical properties, physical properties, rheology	Food, food processing, food safety, food-borne pathogens, food spoilage, food supply, food ingredients, nutrients, food packaging, sensors, MRI	Measurement technology to better understand food properties and nutrients: nondestructive techniques like magnetic resonance imaging to investigate rheological properties of food; computational fluid dynamic modeling of complex phenomena in foods; bioinformatics to better understand food nutrition and enhance food engineering; reliable methods for screening and assessing ingredient functionality; sensors for online real-time control and monitoring of food processing

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Technology Foresight: Food Research Trends: 2003 and Beyond	2003	Advanced sensors and detectors for food-borne pathogens (e.g., hand-held pathogen detectors), toxins and contaminants could revolutionize the means by which the safety of the food supply is monitored and controlled, as well as industry response to potential crises events involving the food supply. There is an immediate R&D need for real-time analyses of food constituents to combat terrorism.	Food science historically evolves slowly. Current technology is inadequate for real-time detection of pathogens and food contaminants.	Pathogens, spores, meat tenderness, food spoilage, food adulteration, toxins.	Food, food processing, food safety, food-borne pathogens, food spoilage, food supply, food ingredients, nutrients, food packaging, MEMS, nanotechnology, sensors	Systems to provide real-time detection of food-borne pathogens and analysis of food constituents to ensure food safety and combat terrorism: microelectromechanical systems (MEMS) and nanotechnology in the design of biosensors for detecting pathogens, spores, meat tenderness, food spoilage, and food adulteration; techniques to trace dairy products to source cow to meet consumer safety requirements; real-time detection of microorganisms in food using a variety of methods; DNA/RNA chip technology (lab-on-a-chip) to speed detection and analysis of toxins in food; food pathogen sensors as small as dust; real-time detection systems for verification/validation of intervention technologies used in Hazard Analysis and Critical Control Point HACCP systems
What Businesses Need to Know About FDA's Plan to Combat Obesity	2005					
Nanoscale Science and Engineering for Agriculture and Food Systems	2003	Achieve greater ability to ensure agricultural security, environmental preservation, and food and water safety through bioanalytical nanosensors.	Necessity to improve upon current detection capabilities for agriculture and food systems	Specificity, reliability, accuracy, reproducibility, robustness, stability, and response and processing time of sensors	Bioanalytical nanosensors, pathogens, nutrients, contaminants, detection, agriculture, food, nanotechnology	Nanosensors for pathogen, nutrient, and contaminant detection: bioanalytical nanosensors, new assay systems, sample retrieval systems, and fundamental mechanistic sensor research and modeling
Nanoscale Science and Engineering for Agriculture and Food Systems	2003	Enable continuous tracking and recording of the history a particular agricultural product (from storage, shipping, deliver to store, and transfer to consumer).	Necessity to improve upon quality assurance of the safety and security of agricultural products	Reliability, accuracy, stability, lifetime of identity preservation and tracking devices	Identity preservation, tracking, biodegradable sensors, detection devices, data loggers, agricultural products, food, nanodevices, nanotechnology	Nanodevices for identity preservation and tracking: biodegradable sensors for quantifying metabolic process energetics; nanothermal device/data loggers; pesticide and fertilizer detection devices/data loggers
Nanoscale Science and Engineering for Agriculture and Food Systems	2003	Develop nanoscale devices with the ability to detect and treat infection, nutrient deficiency, or other health problem, long before the evidence of symptoms at the macroscale.	Current limitations of preventative treatment for infections and disease in plants and animals	Sensing and monitoring capabilities, time-control, spatial targeting, self-regulation, and remote-regulation of smart delivery systems	Health monitoring, smart delivery, agriculture, nanoscale devices, nanotechnology	Health monitoring/smart delivery devices for plants and animals

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Nanoscale Science and Engineering for Agriculture and Food Systems	2003	Utilize higher-resolution devices for the separation of enzymes and other biomolecules that are key catalysts for industrial biotechnology; novel methods for observing single molecule events for assessment of protein engineering efforts focused on important industrial polysaccharide degrading enzymes; novel lab-on-a-chip proteomics technology for microbial biocontrol agent assessment; rapid and reliable DNA methods for detection of phytotoxins and pathogens in digested and composted animal waste to determine subsequent safe use in agriculture; and highly sensitive monitoring instruments for food safety, product quality, and environmental factors.	Necessity for increased efficiency and quality of agricultural production and food storage, enhanced safety of the food supply, and new functionality (value-added products) for food and agricultural commodities	Enzymatic processes, microbial kinetics, molecular ecology, metabolic pathways, food safety and quality	Nanodevices, molecular biology, cellular biology, DNA, proteins, enzymes, characterization, agriculture, food, nanotechnology	Nanodevices for molecular and cellular biology: nanoseparation, identification and quantification devices for characterization studies of molecules, DNA, and cells for food, nutraceutical, and pharmaceutical applications; nanobiorectors; advanced instruments for DNA and protein identification and manipulation
Nanoscale Science and Engineering for Agriculture and Food Systems	2003	Enhance environmental quality by detecting and mitigating environmental contaminants. Manage global carbon dioxide better; make more efficient use of water, fertilizer, and pesticides; decrease salt build-up and nutrient leaching from soils; and decrease agricultural pollution.	Current limited understanding of natural nanoparticles and nanoparticles produced by agriculture results in the inability to fully utilize these natural resources or mitigate any negative effects.	Transport and toxicity of nanoparticles, chemical and physical properties of soil in the nanoscale, nanoparticles in the global carbon cycle, role of nanoparticles in water retention and conditioning of soils	Soil, water, air, characterization, environmental quality, agriculture, food, nanoparticles, nanotechnology	Characterization of nanoparticles in the soil, water, and air
Nanoscale Science and Engineering for Agriculture and Food Systems	2003	Achieve longer shelf life and less contamination of food products; bio-selective surfaces for early detection of plant and animal pests and pathogens; smart detectors for spoilage organisms; "smart one season use" field microsensors for pest and pathogen detection and improved soil health; nanosurfaces for pollutant, pathogen, and bioactive molecule remediation prior to processing; and anti-fouling nanosurfaces for food processing equipment and food products.	Current limited understanding and application of nanomaterials to agricultural processing and food preservation	Transition from bulk to nanoscale behavior and chemical behavior, changes in morphology, texture, chemistry, bioselectivity, physiochemical properties, food safety and quality	Mechanics, characterization, models, sensors, detection, surfaces, shelf life, preservation, agriculture, food processing, nanomaterials, nanotechnology	Fundamental nanomaterials science research: nanomaterial mechanics; measurement methods and techniques to apply multiscale modeling to agricultural systems; characterize and model physiochemical properties of natural and synthetic surfaces; characterize and model biological system self-assembly as templates for nano-self-assembly
Coatings on Glass Technology Roadmap Workshop	2000	Innovative, durable, online sensors and process control will enable economic mass production of coated glass products with higher yields and lower defect rates.	There is a lack of online process control and poor understanding of how to automate coating processes.	Size and density coating defects, optical and electrical film properties, glass surface cleanliness, precursor and effluent concentrations, coating coverage	Process control, automation, sensors, coatings for glass	Durable, online sensors and (feedback) process control that can be used to automate coating processes for flat, container, specialty glass, and fiber glass.
Glass Industry Technology Roadmap	2002	Develop robust atmospheric gas species sensors, 3-D thermal mapping and velocity measurements, and in situ molten glass property sensors.	Current sensors and related process controls cannot accurately and cost-effectively measure and control melting, refining and forming processes in real time.	Robust, longer lasting, more reliable sensors needed	Glass, combustion, temperature, sensor, real-time, NOx, emissions, furnace, fuel,	Improve efficiency and optimize performance by providing real-time data on conditions in the glass melt and the combustion atmosphere in the furnace. Allow appropriate adjustments.
Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	The apparatus should take into account the release mechanism and the physical properties of the product (size and stability)	Current apparatus for in vitro testing are designed for oral and transdermal products and may not be optimal for controlled release parenteral products; clogging of the needles	Release mechanism, physical properties, apparatus geometry and hydrodynamics, viscosity, morphology of suspension, syringe size, needle size	Apparatus, release mechanism, physical properties	Apparatus geometry and hydrodynamics

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Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	Achieve in vivo relevance by considering physiological variables: body temperature and metabolism (both can significantly affect blood flow), muscle pH, buffer capacity, vascularity, level of exercise, volume and osmolarity of the products, tissue response; identification and potential minimization of variability with IVIVC	Lack of information on clinical performance of in vitro release (efficacy, safety)	In vitro-in vivo performance and correlation; physiological variables	In vivo, in vitro, physiological variables	Method development for in vitro testing with regard to clinical outcome (bio-relevance): design in vitro methods based on in vivo release mechanisms; in vitro-in vivo correlation (IVIVC)
Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	More extensive bio-data can be obtained using animal models, including tissue levels at the local site. Serial tissue samples might be used to compare product performance before and after manufacturing changes for controlled release parenterals with tissue-specific delivery.	Plasma levels may not be the best measure of in vivo behavior for controlled release parenteral products intended for local delivery or targeted release; limitation of the types of controlled release parenterals that can be developed	Tissue distribution, pharmacokinetic information, in vivo behavior	In vivo, tissue, pharmacokinetic, animal model, biopolymers	Animal models in release testing for tissue distribution, pharmacokinetic information, qualifying inactive ingredients (biopolymers)
Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	Develop bio-relevant accelerated drug release that does not alter the mechanism of drug release, but only speeds it up for extended release products.	Safety considerations, need to avoid any changes in the mechanisms of drug release from factors such as polymer transition and degradation temperature	Drug release rate and mechanism	In vitro, rate, mechanism	Validating accelerated in vitro release rates
Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	Appropriate degradation profiles, target integrity, and safety and efficacy data will help move toward the approval of new controlled release parenterals.	Characterization of stability, sterility is necessary for understanding the parameters in which in vivo and in vitro drugs can safely and effectively function.	Drug stability, internal/external sterility, foreign particulate requirements	In vivo, in vitro, stability, sterility	Characterization of drug stability, sterility: shelf life, in vivo, in vitro
Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	Appropriate particle size and product specifications will help move toward the approval of new controlled release parenterals. Make available a list of tests, procedures, and acceptance criteria for the product.	Acceptable particle size ranges may vary for different controlled release parenteral systems. Large particles may have a significant effect on product performance and safety, and may cause capillary blockage when injected intravenously. Particle size may also affect release rates and syringability of the product. There is a lack of standardized specification data for products.	Physical properties, chemical properties, potency, sterility, product-specific specifications	In vitro, in vivo, physical properties, chemical properties, specifications	Particle size, product specifications for dispersed system controlled release parenterals
Assuring Quality and Performance of Sustained and Controlled Release Parenterals	2002	Obtain greater understanding of the rate and release of active drug at the site of action for comparison with other pharmaceutically equivalent drug products.	Lack of a clear understanding of the way liposomes and controlled release parenteral products and their contents are handled in the body (in vivo)	Bioavailability, bioequivalence	In vivo, bioavailability, bioequivalence, pharmaceutical equivalence	Assessment of bioavailability and bioequivalence
Challenge and Opportunity on the Critical Path to New Medical Products	2004	Solve new medical product development problems, which would result in safe products that benefit patients and eliminate impending failures more efficiently and earlier in the development process.	The inability to better assess and predict product safety leads to failures during clinical development and, occasionally, after marketing. The inability to accurately predict the industrialization process prevents some products from being produced on a large scale.	Standards, assays	Medical products, standards, predictive tools, imaging technologies, genomics, proteomics, bioinformatics systems, product safety	Develop performance standards and predictive tools (assays, standards, computer modeling techniques, biomarkers, and clinical trial endpoints) that make the development process of medical products more efficient and effective. Apply technologies such as genomics, proteomics, bioinformatics systems, and new imaging technologies to the science of medical product development in order to provide tools to detect safety problems early, identify patients likely to respond to therapy, and lead to new clinical endpoints.
Challenge and Opportunity on the Critical Path to New Medical Products	2004	Enhance safety of transplanted human tissues. Employ proteomic and toxicogenomic approaches that provide sensitive and predictive safety assessment techniques. Improve predictive power obtained from in silico (computer modeling) analyses such as predictive toxicology.	Inadequate techniques for assessing drug liver toxicity, methods to identify gene therapy risks based on assessment of gene insertional and promotional events	Biological	Medical products, predictive tools, human immune response, product safety	Improved predictors of human immune responses to foreign antigens and to assess the risk of new drugs such as those causing heart rhythm abnormalities

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Challenge and Opportunity on the Critical Path to New Medical Products	2004	Improve trial design and predict outcomes through model-based drug development, and improve predictive software to model the human effects of design changes for rapidly evolving devices.	Quantitative clinical trial modeling using simulation software needs refinement. Much development work and standardization of the biological, statistical, and bioinformatics methods must occur before these techniques can be easily and widely used.	Simulation software	Medical products, models, simulation software, predictive tools, bioinformatics	Mathematical and statistical characterizations of the time course of diseases and drugs using available clinical data
Challenge and Opportunity on the Critical Path to New Medical Products	2004	There are multiple innovations across areas. For example, developing test standards for coronary stent compressibility will decrease the likelihood of failed designs and allow smaller clinical trial programs.	N/A	Standards, biological	Medical products, standards, stem cells, bioengineered tissues	Characterization procedures and standards for expanded stem cell and other cellular products, bioengineered tissues, and implanted drug-device combinations
Challenge and Opportunity on the Critical Path to New Medical Products	2004	Improve medical product manufacturing efficiency and increase flexibility while maintaining high quality standards.	Insufficient research and data sharing	Sensors, process variables	Medical products, sensors, controls, manufacturing, quality standards	Automated sensors that monitor and control processes
Fourth Report on Needs in Ionizing Radiation Measurements and Standards	2004	As new isotopes are developed, NIST traceable standards and appropriate measurement techniques for radioactive isotopes used in nuclear medicine need to be developed.	Each specific application of a radioactive isotope needs to be studied and understood in order to develop transferable standard measurement systems.	Specific isotope properties, imaging system properties, decay methods	Transfer standards, dose calibrations, nuclear medicine, therapeutic radionuclide, diagnostic radionuclide, radiation, radiation protection	Medical: diagnostic and therapeutic uses of ionizing radiation
Fourth Report on Needs in Ionizing Radiation Measurements and Standards	2004	Establish standards for 3D dosimetry, quality assurance and treatment verification for conformal radiation therapy.	3D measurements need to be accurate to less than 1mm because of the intense focusing of the radiation beams if full benefits of this therapy are to be achieved. Measurements systems need to be standard and transferable to hospitals and other facilities.	Spatial dose resolution, new materials for dosimeters, chemical changes induced by the radiation in tissue-equivalent solids or gels	Gel dosimetry, tissue-equivalent solids or gels, CT, MRI, spatial distribution, radiation protection, homeland security	Medical dose mapping systems for 3D conformal radiation therapy and intensity modulated radiation therapy, improved and increased sensitive instruments and traceable standards for radiation protection
Fourth Report on Needs in Ionizing Radiation Measurements and Standards	2004	Numerous factors affect the embitterment process, such as the fast-neutron fluence, energy spectrum and chemical composition of the steel. Accurate predictions of the end-life of the materials requires complex calculations and comparison with measured data.	During power operations of light water cooled pressurized water nuclear power reactors, radiation-induced embitterment will degrade specific mechanical properties important to maintaining the structural integrity of the reactor pressure vessel.	Neutron energy spectrum, neutron fluence, embitterment rates, fracture toughness	Energy spectrum, fluence, nuclear power reactor operations, homeland security	Sustain NIST traceable neutron dosimetry protocols for the nuclear power industry.
Fourth Report on Needs in Ionizing Radiation Measurements and Standards	2004	Continue development of more sensitive measurement techniques traceable to NIST standards. Continue development of transferable standards and accreditation standards for radiation monitoring laboratories.	Greater demand for more sensitive instruments and standards traceable to NIST and more strict accreditation for laboratories	Sensitivity, analytical speed, accreditation programs, new measurement techniques, improved calibration techniques, neutron energy spectrum neutron fluence, embitterment rates, fracture toughness	Dose, radiation, accreditation, analytical methods, contamination, traceability, environmental monitoring, energy spectrum, fluence, nuclear power reactor operations	Improved and increased sensitivity instruments and traceable standards for radiation protection

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Innovation, Demand, and Investment in Telehealth	2004	Standards are a means by which interoperability is achieved; it will contribute to resolving interoperability and integration issues in the long term. Benefits include: the ability to plug and play devices and applications as required; increased safety with compliant devices and applications comply with industry requirements; greater satisfaction of users in knowing devices and applications are tested and compliant; reduction of uncertainty means better management of clinical risk; assuring compliance will contribute to greater credibility and therefore to consultation volumes; compliant performance can assist with costing of services because of the sameness of workflow among providers; standard performance can support evidence-based practices.	In some cases, there is an excess of standards developed by multiple organizations. In others, there are insufficient standardized nomenclatures and taxonomies. Many telehealth services cannot be performed within or across delivery systems. Physicians are unlikely to embrace advancements in telehealth applications without standards that make telehealth technologies easier to use or that enable interoperability among disparate systems.	Standards, medical protocols, interoperability	Telehealth, technical standards, data standards, interoperability, integration, safety	Industry-wide telehealth technical standards, including data standards, integrated with medical protocols
Innovation, Demand, and Investment in Telehealth	2004	N/A	N/A	Clinical efficacy	Telehealth, standards, clinical efficacy	Standardized tools to measure clinical efficacy of telehealth applications
Innovation, Demand, and Investment in Telehealth	2004	Obtain real-time biochemical measurements and minimally invasive therapy in military medicine.	N/A	Physiology, physiological	Telehealth, military medicine, physiological sensors	Physiological sensors
Innovation, Demand, and Investment in Telehealth	2004	Improve detection of chemical/biological/radiological /nuclear/explosive (CBRN/E) attacks	N/A	Chemical, radiological, biological	Chemical/biological/radiological/nuclear/explosive (CBRN/E), sensors, homeland security	Sensors and surveillance devices to improve homeland security alert capabilities
National Institute of Biomedical Imaging and Bioengineering DRAFT Strategic Plan	2005	N/A	N/A	Biological	Medical imaging, bioimaging, ioengineering, technology performance data, research studies, clinical trials	Ability to evaluate the impact of technology performance data on the outcome of research studies and clinical trials
National Institute of Biomedical Imaging and Bioengineering DRAFT Strategic Plan	2005	Various innovations are possible. For example, glucose-activated insulin-delivery systems could effectively replace the function of the pancreas for people with diabetes.	N/A	Chemical, physiological	Biomedical imaging, bioengineering, chemical sensors, physiological sensors, drug delivery	Smart sensors that will use chemical and physiologic signals from the body to release drugs at the right site, at the right time, and at the right dose
National Institute of Biomedical Imaging and Bioengineering DRAFT Strategic Plan	2005	Various innovations are possible. For example, molecular imaging and high throughput technologies could evaluate genes for screening disease.	N/A	Biological, molecular	Biomedical imaging, bioengineering, molecular events, genetic screening	Ability to detect early, preclinical, molecular events to identify patients at risk
NIH Roadmap for Medical Research	2005	Develop highly innovative and sensitive tools to identify and quantify cellular metabolites, and advanced technologies and models to address a broad range of challenging biomedical research problems and help predict the human body's response to disease, injury, or infection.	Inability to quantitatively measure the activity, translocation, and interactions of intracellular protein molecules; lack of technologies that can effectively measure, with sufficient sensitivity and precision, the diverse range of metabolites and their dynamic fluctuations within cells	Proteomic and metabolic behavior, pathways, and networks, biological	Proteome, metabolome, cells, biological pathways and networks, characterization tools	Characterization tools for proteomes, metabolomes, and their respective networks

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
NIH Roadmap for Medical Research	2005	Obtain improvement of one to two orders of magnitude in the ability to detect and image specific molecular events in vivo, and increase resolution of the images within living cells by 10 to 100-fold for greater understanding of cellular biology. Ultimately, these efforts will lead to the identification of novel targets for the treatment of disease.	Poor sensitivity and specificity of currently used molecular probes, especially in living cells; need for faster, more efficient, and more accurate screening systems to identify small molecules and explore the biological mechanisms within living cells	Molecular function and biological mechanisms/processes of living cells and tissues	Molecules, cells, probes, imaging, biological processes, characterization, in vivo	Molecular and high-resolution cellular probes and screening instrumentation for molecule/cell characterization
NIH Roadmap for Medical Research	2005	Develop diagnostic tools and nanomaterials/devices for treatment of disease and repair of tissues.	Current inability to determine the compatibility and safety of the physical and chemical properties of nanomaterials inside the body	Physical properties, chemical properties, compatibility, safety	Nanomedicine, nanotechnology, physical properties, chemical properties, tissues,nanoscale, biological	Metrology to support the development of nanomedicine
NIH Roadmap for Medical Research	2005	More sensitive and efficient testing of major chronic disease symptoms and functioning is needed. Ultimately, such a system will also be useful in clinical practice to assess patients' treatment responses and to inform them of therapy modifications.	Current assessment of chronic disease outcomes relies heavily on subjective reports of symptoms and health-related quality of life items, with no easy comparison among clinical studies.	Chronic disease symptoms and functioning (e.g., pain, fatigue, quality of life), physiological	Patients, symptoms, assessment	Patient-Reported Outcomes Measurement Information System (PROMIS)
NIH Roadmap for Medical Research	2005	Maintain interoperable networks and seamless data and sample-sharing across studies.	Lack of common infrastructure results in simultaneous, but independent studies that cause researchers to sometimes duplicate data that already exist because they are either unaware of, or do not have access to the data.	Infomatics infrastructure, network performance, standards, interoperability	Standards, data, network infrastructure	Standardizing data reporting
The Medical Imaging Technology Roadmap: An Overview	2004	N/A	N/A	Pharmacotherapeutic imaging, bioimaging	Medical imaging, tumors	Improved sensitivity in techniques to measure individual tumor responsiveness
The Medical Imaging Technology Roadmap: An Overview	2004	Data standards will be required in order to collect, collate and compare data across sites and jurisdictions. Full integration in health care and research facilities will only be possible if standards for image display, recording, transmission and interpretation are developed and adopted by all imaging equipment and post-processing developers and vendors.	N/A	Data standards	Medical imaging, data standards, bioimaging	Standard data structures and processes to support clinicians
The Medical Imaging Technology Roadmap: An Overview	2004	The technology is critical to making a cost-effective X-ray flat-panel imagers in competition with the major approach using cesium iodide phosphor layers. International Electrotechnical Commission and National Electrical Manufacturers Association standards have to be developed.	N/A	Radiography and fluoroscopy standards	Medical imaging, radiography standards, fluoroscopy standards, X-ray flat-panel imagers, bioimaging	Standards are needed for radiography and fluoroscopy systems' large-area deposited direct converter. This is a means for making X-ray-sensitive direct conversion layers that should be compatible with thin-film active matrix array technology, preferably by evaporation or other thin-film process directly onto the thin-film transistor without thermal or other damage to the substrate.
The Medical Imaging Technology Roadmap: An Overview	2004	Advances in volumetric measurement for diagnostic and therapeutic techniques.	Volume measurement techniques based on 2-D imaging use only simple measures of the width in two views and assume an idealized shape to calculate volume. This practice potentially leads to inaccuracy and operator variability.	Volume	Medical imaging, volumetric measurements, bioimaging	Improved volumetric measurement techniques: diagnostic (e.g., obstetrics) and therapeutic decisions (staging and planning) often require accurate estimation of organ or tumor volume

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Nanobiotechnology	2003	Employ microfabricated platforms with integrated nanoscale components for low-cost portable devices that are able to analyze samples from body fluids and gases without major time delays. Also, achieve high-throughput systems with the possibility of single-molecule detection for biological material analysis.	Necessity to base future medical practices on early detection and prevention	Biological material properties, selectivity, specificity, response time	Ex vivo, diagnostic testing, biological systems, nanoscale, nanotechnology	Analytical tools for improved ex vivo diagnostic testing and laboratory techniques
Nanobiotechnology	2003	Employ new techniques to probe molecules and molecular activities at the nanoscale with the highest possible specificity and time/spatial/chemical resolution. Obtain a quantitive understanding of information through the integration of complementary imaging modalities, and ultimately achieve the ability to direct nanostructures to specified locations in biological systems to probe the environment, serve as contrast markers, deliver chemicals/drugs, sense the response, and potentially even regenerate the surrounding tissue.	Limitations in the ability to observe molecular events and to track the distribution and kinetics of molecular probes, drugs, and environmental agents within a whole animal or human under varying physiolocal conditions	Quantitive understanding of biological systems at the nanometer scale; sensitivity, specificity, resolution (time, spatial, chemical) of imaging technologies; biocompatibility	Bioimaging, sensors, probes, biological systems, biocompatibility, molecular, nanoscale, nanotechnology	Advanced imaging technologies, nanoscale sensors, environmentally sensitive molecular probes
Nanobiotechnology	2003	Obtain ability to derive detailed understanding of how cells of all types sense external and internal signals within the context of their particular three-dimensional environments and how these signals are processed to yield particular responses. Ultimately, obtain the ability to identify cell pathosis and return an altered cell to normal operational parameters, or remove it before it causes the derangement of other cells.	Limited ability of current technologies to provide quantitative information about how cellular components and molecular networks work together in living systems	Cellular structure, form, mechanics, functions, responses (secretion, growth, differentiation, motility, contractility, apoptosis); biocompatibility	Cell, in vivo, probes, biological systems, biocompatibility, nanoscale, nanotechnology	In vivo analysis of cellular processes and measurement of cellular response to a variety of physical perturbations through quantitative analytical tools: biocompatible nanoprobes, microfluidic devices, biomimetic devices, and optical/scanning/detection probe schemes
Nanobiotechnology	2003	Obtain the ability to rebuild functional modules that recapitulate biological functions de novo from the lower end of the nanoscale to devices on the same size scale as organelles and cells (bottom-up assembly). The application of this ability to medical purposes includes going beyond current drug paradigms for treatment of disease into new modalities of treatment that combine today's molecular agents with nanoscale biomechanics. Target areas include cancer therapy, tissue regeneration, and immune modulation.	The need to target therapy of human diseases more effectively requires understanding the process of going from genomic information to live assemblies of biomolecular systems.	Mechanical and fluidic forces, diffusive and active transport, self-assembly of cells from genomic information, biomolecular system organization	Cells, ex vivo, bottom-up assembly, model, biological/biomolecular systems, nanoscale, nanotechnology	How cells work through bottom-up assembly of biological nanosystems ex vivo; physical model of the cell as a machine
Nanobiotechnology	2003	Achieve safe development of nanomaterials for medical applications.	A large gap still exists at the interface between biological and chemical/mechanical/solid nanomaterials.	Compatibility, toxicity, safety, biological, chemical, physical	Compatibility, toxicity, safety, biological, nonbiological, nanomaterials, nanotechnology	Compatibility between biological and nonbiological nanotechnology materials
Consensus Roadmap for Defeating Distributed Denial of Service Attacks: A Project of the Partnership for Critical Infrastructure Security Version 1.10	2000	Cyber attacks often increase ISP load and traffic volume, monitoring anomalous volume changes may enable early detection of new cyber threats	N/A	ISP load volume, ISP traffic volume	ISP, cyber attack, traffic volume, load volume, early warning	Establish load and traffic volume monitoring at ISPs to provide early warning of attacks

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Consensus Roadmap for Defeating Distributed Denial of Service Attacks: A Project of the Partnership for Critical Infrastructure Security Version 1.10	2000	N/A	N/A	Router access	Router, access control, firewall	Support the development of tools that automatically generate router access control lists for firewall and router policy
Consensus Roadmap for Defeating Distributed Denial of Service Attacks: A Project of the Partnership for Critical Infrastructure Security Version 1.10	2000	N/A	N/A	Cyber intrusion, cyber security	Cyber intrusion detection	Test deployment of and continue research on anomaly-based and other forms of intrusion detection
Consensus Roadmap for Defeating Distributed Denial of Service Attacks: A Project of the Partnership for Critical Infrastructure Security Version 1.10	2000	N/A	N/A	Cyber security, cyber intrusion, privacy invasion	Non-invasive monitoring, law enforcement, forensic tools,software assurance	Research better forensic tools and methods to trace and apprehend malicious users without forcing the adoption of privacy-invading monitoring
Science and Technology: A Foundation for Homeland Security	2005	Develop advanced materials for radiation detection systems: ability to find and remove contamination (tailored to the building materials found in urban environments) to avoid costly demolition in affected areas; and reduction of economic and psychological impacts of the dispersal of radioactive contamination.	Necessity to better detect and identify radioactive materials to meet a wide variety of civilian and defense requirements; requirements for methods of decontamination and controlled clean up of radioactively contaminated buildings and critical infrastructure	Radioactive particle dispersion and behavior, material properties	Radioactive, detection, decontamination, models, material properties, radiation	Metrology to support radiation detection and decontamination systems; models to predict the dispersion and behavior of radioactive particles in the atmosphere following nuclear/radiological incidents
Science and Technology: A Foundation for Homeland Security	2005	Validate methods for rapid detection of microbiological agents in foods for their protection and recovery from threat agents.	Necessity to improve upon identifying threat agents in the food supply and methods to protect food products	Microbiological activity and threat agents in food	Microbiological activity, threat agents, diagnostic tests, food	Rapid diagnostic tests for agents that may pose a threat to the U.S. agricultural system
Science and Technology: A Foundation for Homeland Security	2005	Improve response time to identification requests and improvement in the performance of face recognition systems in "real world" environments, which involve changes in pose angle, facial expression, lighting, and background.	Current lack of complete standards for biometric identification systems and their interoperabililty	Standards, interoperability, performance	Biometrics, interoperability	Standards for biometric system interoperability, data interchange, and performance assessments
Science and Technology: A Foundation for Homeland Security	2005	Maximize screener performance at airports and within other transportation systems so that individuals with intent and capacity to harm can be identified before harm occurs. Develop behavioral biometrics (measurable behavior traits acquired over time), content analysis in foreign documents and speech, alternatives to the polygraph, and improvements in intelligence analysis.	Necessity to increase understanding of thought processes, learning, and decision making in individuals and teams	Behavioral biometrics, psychological and physiological changes during acts of deception	Behavioral biometrics, polygraph, deception	Modeling the underlying memory, attention, and salience processes that are engaged when an individual lies, and assessing the usefulness of polygraph signals, saccadic eye movement, cardiovascular changes, and voice stress in the detection of deception
Science and Technology: A Foundation for Homeland Security	2005	Enable rapid prediction dissemination to federal, state, and local responders for efficient protection, detection, countermeasures, and decontamination following a chemical, biological, or nuclear terrorist event.	Necessity for better predictive tools of hazardous environmental occurrences in order for efficient and appropriate response	Chemical, biological, nuclear threat detection	Risk assessment tools; models; sensors; biosurveillance; chemical, biological, nuclear threat detection, first responders	Models, tools, and sensors for chemical, biological, and nuclear threat detection; atmospheric dispersion modeling and other atmospheric hazard prediction products for biosurveillance of incidents of national significance; integrated sensors with the operation of ventilation systems, enabling contaminated air to be redirected and allowing time for safe evacuations; rapid risk assessment tools needed both by responders and by those who must make longer term "how clean is safe" decisions following any incident

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Science and Technology: A Foundation for Homeland Security	2005	Reduce vulnerability of buildings to chemical, biological, and radiological aerosols.	Current limitations of buildings to provide protection against chemical, biological, and radiological aerosols	Material properties and performance	Building materials, performance, aerosols	Methods to test high performance building materials for resistance to chemical, biological, and radiological aerosols
Science and Technology: A Foundation for Homeland Security	2005	Improve security of the existing cyber infrastructure and a foundation for increased security in the future.	Current vulnerabilities of the Internet to cyber attack and abuse	Cyber security, software and Internet security	Security, software, networks, Internet	Metrology to support cyber security: secure software development, software assurance, cyber security assessment, wireless security, cyber attack traceback, detection of insider threats
Sensor Systems for Biological Agent Attacks	2005	Provide the earliest possible warning of biological attack for extended targets, such as military bases, and reduce false alarms from the large amounts of biological material normally present in the atmosphere.	Currently, there is no fielded standoff biological agent aerosol detection capability, and no fielded standoff capability to identify threat biological agents once a biological aerosol has been detected.	Detection range, response time, ability to discriminate between biological threat agents and expected backgrounds, biological activity	Standoff detector, biological agent aerosol, infrared, ultraviolet, modeling, simulation	Development of nonspecific standoff detectors is needed for field capability assessment, concept of operations, and modeling and simulation of projected performance. Development of advanced standoff techniques is needed for hybrid infrared-ultraviolet standoff biodetection, advanced ultraviolet resonant Raman scattering, and passive infrared detection for longer ranges or more specific detection.
Sensor Systems for Biological Agent Attacks	2005	Achieve accurate and rapid detection of threat biological agents with reduced false alarm rates, and the ability to differentiate a rapid biowarfare agent release from the more gradual fluctuations of the natural background.	Inability to detect very low concentrations of aerosolized biological agents	Detector sensitivity to particle size, shape, fluorescence, and concentration; biological activity	Spectroscopic point detector, biological agent aerosol, sensitivity	More capable nonspecific spectroscopic point detectors
Sensor Systems for Biological Agent Attacks	2005	PCR detection can potentially provide attack confirmation and identification of organisms involved in 5 to 15 minute response times. rRNA may provide biothreat agent identification in one to several minutes, thereby avoiding time-consuming amplification cycles of many nucleic acid sequencing arrays.	Extended analysis times (15 to 60 minutes), which is not suitable for detect-to-warn applications; determination of the extent to which sensitivity and specificity must be sacrificed in moving to the detect-to-warn timelines of less than 5 minutes and preferably 1 minute	Detector sensitivity, specificity, response time to biological threat agents, biological activity	Nucleic acid sequence-based identification, PCR, rRNA, sensitivity, specificity, response time	Nucleic acid sequence-based identification: integrated and fully automated polymerase chain reaction (PCR) system that includes sample collection, preparation, and analysis; potential and limitations of ribosomal RNA (rRNA) detection
Sensor Systems for Biological Agent Attacks	2005	Identify biological agents with the speed, sensitivity, and specificity required for detect-to-warn applications, with very low false alarm rates and a 2 minute or less overall detection time.	Mass transport of the antigen to the molecular binding site limits response times; insufficient specificity and nonspecific binding contribute to false alarm rate	Structural and binding characteristics, sensor sensitivity, selectivity, false alarm rate, biological activity, threat assessment	Structure-based detection, sensitivity, selectivity, false alarm rate, response time, mass transport	Improved structure-based detection of biological threat agents
Sensor Systems for Biological Agent Attacks	2005	Obtain ability to use mass spectrometry as an option for identifying biological agents with limited reagent consumption in the presence of complex environmental backgrounds that include the concentration, diversity, and variability of naturally occurring microorganisms and inorganic particles that are expected to be present in deployment circumstances.	Limited work has been conducted to determine the potential of mass spectrometry to accurately identify bioagents in circumstances where the agent organism is present with equal or greater numbers of naturally occurring organisms and other background components.	Detection limit, selectivity, reproducibility, total analysis time, molecular characteristics (size, mass)	Chemical-based detection, mass spectrometry, selectivity	Chemical-based detection of biological threat agents using mass spectrometry

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Sensor Systems for Biological Agent Attacks	2005	Employ small, low-cost arrays of rapid semiselective sensors that can be used as a biological smoke alarm for triggering low-regret response measures.	Unacceptable false alarm rate when operated independently; current lack of sensor performance characteristics	Signal-to-noise ratio; sensitivity; selectivity; false alarm rate	chemical-based detection, semiselective sensors, signal-to-noise ratio, sensitivity, selectivity, false alarm rate	Chemical-based detection of biological threat agents using semiselective sensors; identification of detectable biomarkers and/or classes of biomarkers; rigorous characterization of the signal/noise of sensor arrays under environmental operating conditions
Sensor Systems for Biological Agent Attacks	2005	The most probable role in the overall biodetection architecture will be to detect unknown hazardous agents that have not been anticipated. Achieve a more sophisticated, noninvasive methods for detecting rapid biological changes in sentinels that result from exposure to a toxic agent.	Limited demonstrations against most biological agents; currently does not have the sensitivities or response times needed for detect-to-warn applications	Sensitivity, false alarm rate, response time, biological activity, ease of sample preparation, logistical requirements for deployment	Function-based detection, sentinel organisms, sensitivity, false alarm rate, response time, biological activity	Function-based detection: use of sentinel organisms, whole cells, or parts of cells to detect the biological activity of agents
Sensor Systems for Biological Agent Attacks	2005	Achieve comprehensive characterization of interior and exterior background environments for spectral and physical signatures and improved algorithms and techniques to decrease false alarm rates; upgraded airflow control and other response options for effective active defense; and apply infectivity models to detection systems for less than 10 percent infectivity.	Necessity to achieve good performance in detection systems, with low infectivity; the critical impact of biological aerosol background characteristics on the performance of detection systems, which may potentially cause high false alarm rates at very low levels of detection; critical determinants of inherent vulnerability and the ability to respond to warning of an attack include factors that determine airflow within a facility (ability to isolate HVAC zones, building filter quality, etc.)	Interior and exterior facility background characterization, sensor performance, facility vulnerability, airflow, infectivity	Sensor/detection systems, facility environment, background, characterization, performance, false alarm rate, vulnerability, infectivity, airflow control, buildings	Metrology to support sensor system facility defense performance: characterization of local aerosol backgrounds; facility vulnerability analysis; airflow control characterization; infectivity models
Sensor Systems for Biological Agent Attacks	2005	Obtain ability to efficiently compare and evaluate various sensor systems for biological defense systems.	Difficulty to compare results and evaluate progress because of the variety of measurement units used to report results	Performance characteristics: affinity, specificity, speed, false alarm rate, cost, manufacturability	Standards, guidelines, performance, sensors, affinity, specificity, speed, false alarm rate, cost, manufacturability, standards	Standards and guidelines for testing and performance reporting
The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Enhance speed, accuracy and durability with lower power requirements and cost. Improve sensors for first responders.	Current sensor technology is not as sensitive, accurate or robust as desired	Physical, chemical, biological, radiological, nuclear, explosive	Critical infrastructure protection, sensors, CBRNE, sensor networks, first responders, self-diagnosing, self-healing, cyber security	Develop improved physical and cyber monitoring and detection systems. These sensors will have increased sensitivity, be environmentally aware, have higher accuracy, and include both active and passive sensors and robotic platforms. Improved sensitivity of detectors for explosives is particularly vital, especially at long distances. Must also detect chemical, biological, radiological, nuclear, and high-explosive (CBRNE) devices and weapons. Sensor networks also need to be enhanced to be self diagnosing and self healing.
The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Achieve next generation designs and architecture for devices and systems.	N/A	Physical, chemical, nanoscale, biological, materials properties	Critical infrastructure protection, performance modeling, protective materials, structural materials	Develop performance modeling capabilities such as for high-performance concrete, advanced polymer materials and applications of nano- and bio-technology in protective materials and devices.
The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Include structural fire loads explicitly in the design of new structures and retrofit of existing structures.	N/A	Standards	Critical infrastructure protection, fire codes, fire standards, fire safety, first responders, building codes	Develop and implement performance-based fire codes and standards.

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The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Fire sensor information and information from other building controls are needed for greater situational awareness in emergency response decisions and to aid in rerouting egress paths based on environmental conditions. Sensors installed in buildings or carried into the building by responders provide a continuous flow of information about conditions in the threatened structure. Enhances common operating picture.	N/A	Fire	Critical infrastructure protection, fire sensors, first responders, building controls	Improved fire sensors
The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Improve security of entry and access portals.	N/A	Standards	Critical infrastructure protection, standards, sensors, entry and access portals, building security	Standards for security hardened hardware and tamper-proof designs and for maintaining and communicating sensor data coupled with methods to accurately characterize the performance of these systems
The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Improve dynamic situational control.	N/A	Physiological, psychological	Critical infrastructure protection, physiological sensors, behavior, situational control	Reliably determine human behavior, which is essentially qualitative, using quantitative measurements. Employ sensors that can accurately determine a person's physiological and behavioral state.
The National Plan for Research and Development In Support of Critical Infrastructure Protection	2004	Transform how analysis is performed and decisions are made. Improve risk modeling, simulation and analysis for decision support.	N/A	Standards, risk, vulnerability	Critical infrastructure protection, standards, decisions support systems	Standardized analysis metrics and measures across sectors for analysis and decision support systems including standard vulnerability analysis and risk analysis of critical infrastructure sectors and assets.
Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive Detection and Protection	2002	Employ nanostructures that more effectively collect and deliver samples to sensitive, selective sensors (chemical, biological, radiological, electromagnetic, acoustic, magnetic, etc.) with information processing electronics and communication for miniaturized, intelligent sensor suites that can actively respond to homeland defense requirements.	Limitations of current sensor technology to detect chemical, biological, radiological, and explosive elements with the sensitivity and selectivity needed for increasingly complex homeland security needs	Chemical, biological, radiological, electromagnetic, acoustic, magnetic, response time	Sensors, detectors, nanoscale, nanostructures, chemical agents, biological agents, radiological agents, explosive agents, sensitivity, selectivity, response time	Nanoscale sensors and detectors: in-vivo sensing, radiological sensing, remote detection
Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive Detection and Protection	2002	Advanced adsorbent materials (personal and collective protection), separation technologies (protective clothing and filters), neutralization/decontamination of agents, and prophylactic measures	Necessity to evaluate and characterize nano-sized materials for their applicability to novel protection, remediation, and prevention technologies	Physical properties, chemical properties, sensitivity, selectivity, performance	Infrastructure, nanoscale, nanostructures, protection, remediation, prevention, sensitivity, selectivity, performance, characterization	Infrastructure to support the testing and evaluation of nanostructures as selective adsorbents, catalytic materials, clothing/separators/filters, capable disruptors of biological agent function, and prophylactic technologies
A Roadmap for Web Services Adoption: A White Paper by netNumina Solutions	2003	Large scale emergence of Web Services with internal and external integration using Web Services interfaces, and the development of external registries and listing of service providers on such registries (forecasted to occur by 2006).	Incomplete/immature standards lead to a lack of Web Services adoption, stemming from skepticism that includes the use of standard Internet protocols by Web Services, such as TCP/IP and HTTP. These protocols freely pass most corporate firewalls, potentially exposing the service to unauthorized users.	Internet security standards and protocols for Web Services	Standards, protocols, Internet, security, interoperability	Development of standards and protocols related to security, non-repudiation, redundancy, and transport
A Strategic Plan for the Acquisition and Use of Information Technology for the City and County of Honolulu	2004					

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Challenges in Information Retrieval and Language Modeling	2002	Better information retrieval algorithms would increase the quality and performance of cross lingual retrieval, web searches, question answering, distributed retrieval, multimedia retrieval, and information extraction.	There is a large increase in online text available and there is a need to develop better performing information retrieval models.	Information relevance, trust of sources retrieved, performance measurements for information retrieval algorithms, software assurance	Information technology, information retrieval, search engines, IT, queries	Measurements to improve information retrieval from web pages and databases are needed. Develop measures to better determine the relevance of an information source to a specific query. Also, develop evaluation techniques to measure the performance of retrieval technologies. Measure "trust" of information from web pages and include this trust factor in the development of better information retrieval models.
Cyber Security	2005	Improve system security through trust of third-party software.	Verification and validation technologies to ensure that documented requirements and specifications have been implemented; models for comparison and metrics to assure that required standards have been met and to enable evaluation alternatives; technologies to efficiently and economically verify that computer code does not contain exploitable features that are not documented or desired	Software vulnerability, software assurance	Cyber security, software vulnerability, verification and validation technologies, software assurance	Ability to assess whether software implements stated functionality, and only that functionality, by developing tools to assess vulnerability including source code scanning
Cyber Security	2005	Achieve rapid, automated discovery of outages and attacks from monitoring data.	Automated tools to assess compliance or risk	System vulnerability, cyber security, cyber intrusion	Cyber security, system vulnerability, security metrics, security benchmarks, system monitoring	Security metrics and benchmarks to be implemented through system monitoring (on a global or localized level) to ensure they meet declared security policies
Cyber Security	2005	Obtain ability to identify origin of cyber attacks, including trace back of network traffic, and identify attackers based on their behavior.	N/A	Network traffic, cyber security	Cyber security, network traffic	Method to determine the origin of a message transmitted over the internet and automatically determine if it is malicious or benign
Data Storage Devices and Systems Roadmap	2005	Incorporate autonomic computing into real products and solutions.	N/A	Standards, benchmarks	Data storage devices, data storage systems, autonomic	For a marketplace of autonomic technologies, standard benchmarks must be developed in order to enable competing products and approaches to be rigorously compared.
Data Storage Devices and Systems Roadmap	2005	Allow improved file grouping. For example, show that a certain PowerPoint file is related to a set of files for a given project.	N/A	Storage relationships	Data storage devices, data storage systems, storage relationships, file grouping	Ability to automatically detect and discover complex relationships within a storage system
Data Storage Devices and Systems Roadmap	2005	N/A	It is difficult to determine the right priority levels along with the mechanisms for honoring the specified priorities throughout the entire storage system.	Storage workload standards	Data storage devices, data storage systems, storage workload standards, priority levels	Standards to use for mechanism by which applications specify priority on entire workloads or on a request by request basis
Data Storage Devices and Systems Roadmap	2005	N/A	The drive-internal (internal storage device) application programming interface that would be presented to downloaded functions is unknown.	Application programming interface standard	Data storage devices, data storage systems, application programming interface, API	Standardized, open application programming interface (API)
Data Storage Devices and Systems Roadmap	2005	Decrease the cost of deployment of sensor-based networks and increase flexibility.	Ability to manage unbound data flows (presumably by using a combination of cache, flow control mechanisms, data filtering at the storage cell, and data discarding) created by large network of high-frequency sensors	Data flows	Data storage devices, data storage systems, sensor networks, unbound data flows, sensors	Sensors for a variety of purposes that can form dynamic sensor-based networks, and pervasive storage for networks of sensors
Data Storage Devices and Systems Roadmap	2005	Deriving benchmarks that quantitatively assess systems as described is crucial to the success of autonomics. Without a good target, designers of autonomic systems will not be able to compare their systems against the state of the art in a reliable and reproducible way.	The most important challenge to address is how to evaluate aspects of autonomic systems that relate to humans.	System performance	Data storage devices, data storage systems, system performance, performance benchmarks, autonomic computing	Methods and metrics to compare data storage systems not just on their performance capabilities but also on their ability to optimize themselves, configure themselves, heal themselves, and even protect themselves; heterogeneity and its impact should be an axis of any autonomic benchmark suite

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Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Getting Up to Speed	2004	Improved ability to measure time to solution which includes: the time to cast the physical problem into algorithms suitable for high-end computing; time to write and debug the computer code that expresses those algorithms; time to optimize the code for the computer platforms being used; time to compute the desired results; time to analyze those results; and time to refine the analysis into an improved understanding of the original problem that will enable scientific or engineering advances.	Applications areas have productivity problems because the time to program new supercomputers is increasing. While application codes and supercomputing systems have both become more complex, the compilers and tools that help to map application logic onto the hardware have not improved enough to keep pace with that complexity.	Productivity	Supercomputers, programmability, productivity, software assurance, software metrology	Productivity metrics that will measure the programmability of supercomputers
Getting Up to Speed	2004	N/A	The ability to estimate activities involving human effort, whether for supercomputing or for other software development tasks, is primitive at best. Metrics for system overhead can easily be determined retrospectively, but prediction is more difficult.	Performance	Supercomputers, time to solution, system overhead, software metrology	Metrics used to evaluate supercomputer systems should extend beyond performance metrics to consider such aspects of time to solution as program preparation and setup time (including algorithm design effort, debugging, and mesh generation), programming and debugging effort, system overheads (including time spent in batch queues, I/O time, time lost due to job scheduling inefficiencies, downtime and handling system background interrupts), and job postprocessing (including visualization and data analysis).
Getting Up to Speed	2004	There is an effort to develop a new benchmark called the High Productivity Computing (HPC) Challenge benchmark, which will address some of the limitations.	Current benchmarks are relatively insensitive to memory and network bandwidth and cannot accurately predict the performance of more irregular or sparse algorithms. Stream measures peak memory bandwidth, but slight changes in the memory access pattern might result in a far lower attained bandwidth in a particular application due to poor spatial locality. In addition to not predicting the behavior of different applications, benchmarks are limited in their ability to predict performance on variant systems. At best, they can predict the performance of slightly different computer systems or perhaps of somewhat larger versions of the one being used, but not of significantly different or larger future systems.	Performance, data storage, memory, bandwidth	Supercomputers, performance, benchmarks	Benchmarks to predict supercomputer performance across different applications
Global Software Competitiveness... Numerically Speaking	2005					

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High Confidence Software and Systems Research Needs	2001	In combination with descriptions of specific application requirements, domain theories and their associated reasoning tools might be used to specialize tool and language technology into design environments that provide the support necessary for building high-confidence applications in the domain. Such tools would provide greater assurance about domain-specific aspects of system behavior. Another benefit of this research is that the behavior and other properties of systems will become explicit and more available for analysis and prediction. Simplifying the task of modeling would make assurance technology more accessible and usable for developing high-quality software and systems. Automation will reduce human errors and improve the accuracy of models. Successful abstraction and	Research in tools for describing and analyzing system and software behavior is needed. One issue is how to automate the creation of models from software, including software model derivation from widely used software distribution formats such as Java byte code. Automated abstraction is needed to generate models having feasible analyses while preserving validity and correspondence to the real system. Another research issue is how methods currently used for verification and analysis (e.g., theorem proving, model checking) may supplement informal simulation techniques, and how common models may be generated that could be used for both verification and simulation.	Application domains, software assurance	High confidence software and systems, HCSS, application domains, system and software behavior	Need to develop rigorous descriptions of application domains and to use such descriptions in languages and tools. Domain models, captured as formal theories, should provide a basis for rigorous reasoning about software and systems.
High Confidence Software and Systems Research Needs	2001	Real-time accommodation includes the capability for system reconfiguration to recover from system failures and errors, the capability to adapt to and mitigate adverse environmental conditions, and the ability to provide operator warnings and cues.	N/A	System monitoring, software assurance	High confidence software and systems, HCSS, system monitoring	Real-time monitoring methods must be developed for detection, diagnosis, and prognosis of malfunctions and failures in adverse environments and operating conditions. Monitoring must account for unanticipated events as well as those that can be predicted.
High Confidence Software and Systems Research Needs	2001	Improve safe control of physical systems. The availability of this technology would provide a capability that is lacking in current systems built without monitoring, detection, and accommodation capability.	Research is needed in the correlation of sensor data for detection and analysis of non-local failures or attacks and should include how sensors and probes collaborate and share information with each other. Approaches are needed for ongoing evaluation of sensor and actuator effectiveness during system operation. Filtering of data is necessary to limit what and how much data should be collected to maximize the possibility of detecting anomalies. Probes will need to be provided with some degree of real-time data analysis capability. An issue is the performance impact of augmenting sensors, which should be minimal so they do not significantly degrade performance for legitimate users of the system.	Physical, electronic, magnetic	High confidence software and systems, HCSS, sensor calibration, actuator calibration, predictive models, physical systems	Sensor and actuator calibration against predictive models is needed to detect variations that could arise from physical obstruction or interference in the operating environment.

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High Confidence Software and Systems Research Needs	2001	Integrated development and certification practice with rigorous evaluation standards will pave the way for routine, safe exploitation of information technology in future embedded and complex systems. By using evidence from the full range of high confidence software and systems technologies, costly test-based evaluation can be limited, thereby significantly reducing cost in the development lifecycle. This will spur the creation of innovative technologies for next-generation software-centered consumer products and systems.	Historically, statistical reasoning provided the underpinnings for estimating reliability of composite systems. Reliability requirements are formulated statistically, then formally decomposed and allocated to different components of the system. Models of the reliability of physical system components are generally based on estimates of component wear and breakage after extensive testing. Some reliability metrics also incorporate statistical properties of replication-based fault tolerance methods. Software reliability modeling has largely attempted to mimic physical statistical reliability models, but with variants such as "reliability growth models" that treat trends in the interval of operation without failure as a measure of software reliability. Research is needed to establish foundations for evidence that can yield consistent, reproducible evaluation. Tools and technology should better integrate engineering and certification processes. Certifiers should exploit evidence produced during system engineering design and development in order to reduce	Software reliability, software assurance	High confidence software and systems, HCSS, software reliability, system reliability, certification	Quantitative measures for certifying software and systems reliability
IT roadmap to a Geospatial Future	2003	Development of innovative applications that use location sensing will foster location-aware computing.	Despite advances in data acquisition, GPS, wireless communication, and mobile computing, significant research is still needed before location-aware computing can become commercially-viable.	Infrastructure, scalability, adaptive resource management, privacy/security	Location-aware computing, infrastructure, modeling, standards, sensors	Metrology for effective infrastructure deployment: common standards for location-sensing application programming interfaces (APIs); scalability; deployment modeling and analysis; privacy/security mechanisms; mobile sensor sources
IT roadmap to a Geospatial Future	2003	Free users from desktop computers and physical connections to a network to bring geospatial information into real world contexts and revolutionize interaction with the world. Adaptation techniques will allow applications to degrade gracefully when resources such as bandwidth or battery power become scarce.	Mobile environments typically will be resource-poor, physically constrained, and will exhibit variable and unpredictable intensities of resource use.	Mobile environment, bandwidth	Mobility, bandwidth, geospatial information	Metrology to support mobile environments: protocols and mechanisms to authenticate and certify the location of an individual at any given time
IT roadmap to a Geospatial Future	2003	Obtain capabilities to query languages that can reference and model not only past known locations of objects but also their predicted future locations, and for novel indexing schemes that can handle properties of geospatial data such as continuous evolution and uncertainty.	Existing database techniques do a poor job of representing the complexities of geographic objects and relationships. Discrete representations for objects that span a region in space and time are inadequate and can result in inconsistencies and uncertainties. Data models, query languages, indexes, and algorithms must be extended to handle more complex geometric objects, such as objects that move and evolve continuously over time. Integrating the temporal characteristics of a geographic object into a spatiotemporal database is challenging.	Database adaptability of geographic object and relationship representation	Geospatial information, databases, query languages, models, algorithms	Geospatial data models and algorithms
IT roadmap to a Geospatial Future	2003	Ability to locate relevant spatiotemporal data sets, process models, and data mining algorithms, identify appropriate fits, perform conversions when necessary, apply the models and algorithms, and report the resulting patterns. Obtain the capability of finding patterns in complex geospatial objects that move, change shape, evolve, and appear/disappear over time.	Many spatiotemporal data sets contain complex data that exhibit very high dimensionality and spatial autocorrelation. Applying traditional data mining techniques to geospatial data can lead to patterns that are biased or do not fit the data well. Few current data mining algorithms can handle temporal dimensions, and even fewer can accommodate spatial objects other than points.	Spatiotemporal data patterns, data mining models and algorithms	Spatiotemporal, models, algorithms, data mining	Scaleable, robust, nonlinear dimensionality reduction methods (data mining)

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IT roadmap to a Geospatial Future	2003	Ability to depict highly complex, multivariate, multiscale, time-varying geospatial information in ways that facilitate human understanding.	There is a lack of natural and direct manipulation of high-resolution displays of very large data sets and complex process models in real time, poor representation of the uncertainty in geospatial data sets that incorporat spatial autocorrelation, and lack of appropriate balance between realism and abstraction.	Data representation, geospatial information perceptualization	Data representation, geospatial, information perceptualization, algorithms	Methods and algorithms for information perceptualization: representing extremely complex information using surface texture, sound, and visual attributes
Quantum Computation Roadmap, Pt.1	2004	To operate a quantum computer, it is necessary to be able to read out the state of a specific qubit with high accuracy.	Fault-tolerant implementation of linear-optics quantum computing (LOQC) requires high efficiency, discriminating, single-photon devices. For solid state qubits, workable techniques for qubit-specific measurement are not yet in place.	Particle physics	Quantum computing, qubit, linear-optics quantum computing	Qubit-specific measurement capability
Quantum Computation Roadmap, Pt.1	2004	Achieve very fast, reliable, and fully parallel measurement.	Need single-spin readout and further theoretical calculations including: decoherence by the lattice (photons); decoherence due to voltage fluctuations on control gates and readout devices; and decoherence by impurity spins and charges.	Particle physics	Quantum computing, single-spin, decoherence	Achieve single-nuclear-spin detection, measurement, and control
Quantum Computation Roadmap, Pt.1	2004	Fundamental to the entire field of quantum information processing (QIP)	N/A	Particle physics	Quantum computing, quantum information processing, QIP, decoherence	Understand decoherence and the control of deconherence
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Unable to fully characterize qubits	Particle physics	Quantum computing, qubit, nuclear magnetic resonance	Measure: the spectral density of noise generators; and the fidelity of qubit state preparation (solid state)
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Unable to fully characterize two-qubit operations	Particle physics	Quantum computing, qubit, nuclear magnetic resonance	Measure: the fidelity of coherent two qubit logic operations (solids); the fidelity and correlation for preparing Bell states (solids); the relaxation superoperator for 2 qubits (liquids); and the correlations of noise generators for multiple qubit (liquids and solids)
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Unable to fully characterize 3 to 10 physical qubits	Particle physics	Quantum computing, qubit, nuclear magnetic resonance	Measure: the fidelity and correlation of producing a GHZ & W states (solids); the fidelity of producing cat-states for four or more qubits; the fidelity of entanglement swapping; and the scaling of decoherence rates with increasing size of cat states (solids)
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Unable to fully characterize operations on one logical qubit	Particle physics	Quantum computing, qubit, nuclear magnetic resonance	Measure: the fidelity of logical qubit state preparation (solids); and the fidelity of single logical qubit operations
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Unable to fully characterize operations on two logical qubits	Particle physics	Quantum computing, qubit, nuclear magnetic resonance	Measure: the fidelity of two logical qubit operations; and the fidelity and correlation for preparing Bell states of two logical qubits
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Unable to fully characterize operations on 3 to 10 logical qubits	Particle physics	Quantum computing, qubit, nuclear magnetic resonance	Measure: the fidelity and correlation of producing a GHZ state of three logical qubits; the fidelity for preparing the cat state for 4 or more logical qubits; the fidelity of entanglement swapping between logical qubits
Quantum Computation Roadmap, Pt.1	2004	Achieve nuclear magnetic resonance quantum computation.	Inadequate instrumentation	N/A	Quantum computing, tomography, nuclear magnetic resonance	Improve statistical measures for tomography
Quantum Computation Roadmap, Pt.1	2004	Use in the study of fluctuating fields, which affect other quantum-information-processing devices.	N/A	Noise	Quantum computing, ion motion, noise measurement, field fluctuations	Noise measurement through ion motion: ion motion is a very sensitive (tunable) detector of surface field, which causes motional decoherence in an ion-trap quantum computer
Quantum Computation Roadmap, Pt.1	2004	N/A	For internal-state qubits (hyperfine states), coherence times are known to be long but have not yet been measured and are expected to be highly system specific. Motional qubits are expected to have a long coherence time because of neutrals' weak coupling to the environment, but the time has not yet been measured.	Decoherence	Quantum computing, memory decoherence	Measure memory decoherence
Quantum Computation Roadmap, Pt.1	2004	Achieve neutral atom quantum computing.	N/A	Particle physics	Quantum computing, neutral atom quantum computing	Measurements needed to support neutral atom quantum computing include: projective measurements on ensemble, measurements of individual atoms, and continuous measurement and feedback.

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Quantum Computation Roadmap, Pt.1	2004	Make linear optics quantum computing advancements such as optical teleportation without post selection.	N/A	Particle physics	Quantum computing, linear optics quantum computing, optical teleportation, tomography	Measurements needed to support linear optics quantum computing include: optimization of conventional avalanche-based detectors, novel single photon detectors, fast electro-optic control, automated multi-mode tomography, and measures of multi-mode entanglement
Quantum Computation Roadmap, Pt.1	2004	Improve superconducting quantum computing.	N/A	Standards	Quantum computing, superconducting quantum computing, qubits, circuitry	Standards for the fabrication of qubits and associated circuitry including the quality of junctions, reducing flux, reducing charge, reducing critical-current noise, and assessing the best material
Quantum Cryptography Roadmap, Pt. 2	2004	Maintain high confidence in reliability of quantum key distribution system.	Lack of understanding of conditions that ensure adequate security	Standards, software assurance	Standards, quantum key distribution, QKD, cryptography, quantum computing	Standards for quantum key distribution (QKD)
Roadmap for E-Government in the Developing World	2002					
Software 2015: A National Strategy to Ensure US Security and Competitiveness	2005	The National Software Quality Index will serve as a metric for the quality of software products developed and fielded within the United States. Measures for trustworthiness definition and assessment will assess how rapidly changing, plug-and-play software systems can be evaluated for trustworthiness. Stakeholders will be provided with practical and justifiable levels of software trustworthiness for the environments within which they operate, and be informed on interdependencies and trade-offs of software properties that affect trustworthiness.	Unintentional and intentional security exposures, potential for failures, and low survivability when confronted with adverse events	Software security, safety, reliability, survivability, quality, software assurance	Software trustworthiness, security, safety, reliability, survivability, quality, national software quality index	Metrology to support trustworthy software analysis: National Software Quality Index, characterization and assessment of trustworthy software attributes
Software 2015: A National Strategy to Ensure US Security and Competitiveness	2005	Maintain ability to assess the extent to which specific processes and practices make a positive contribution to trustworthy software development. Obtain ability to make correct software development a fast and routine process, with corresponding improvements in manageability and predictability of software projects.	There is limited ability to investigate the processes and practices employed in developing and maintaining software, with their utility often evaluated on the basis of anecdotal evidence. Also, there is an inability to determine and validate the full functional behavior of programs, and the size and complexity of large-scale systems often overwhelm current software engineering methods.	Software engineering practices, software behavior, software assurance	Software engineering, behavior, development, trustworthiness	Metrology to support software development: empirical software engineering evaluation, validation of program behavior
Software 2015: A National Strategy to Ensure US Security and Competitiveness	2005	Improve models for critical non-functional attributes including dependability, quality, and security. Increase support for analysis and reasoning about systems at scale, and have more direct metrics for critical product and process attributes at code level, design level, and requirements level.	Most measures of software in current practice are weak proxies for the actual variables of concern.	Software product and process attributes at all levels of production	Software attributes, artifacts, models, quality, security	Direct evaluation and measurement of software artifacts
The Intel Lithography Roadmap	2002					

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The Lowell Database Research Self Assessment	2003	Several emerging application classes will force data streams to become a first-class part of the database management system (DBMS). The imminent arrival of commercial microsensor devices at low cost will enable new classes of "monitoring" DBMS applications. It will become practical to tag every object of importance with a sensor that will report its state in real time. Monitoring applications will be fed "streams" of sensor information on objects of interest. Such streams will put new demands on DBMSs in the areas of high performance data input, time-series functionality, maintenance of histories, and efficient queue processing. Presumably, commercial DBMSs will try to support monitoring applications by grafting stream processing onto the traditional structured data architecture.	Sensors also suggest the need to deal with more complex forms of information integration. A common case is when sensors are not completely calibrated. A value from a sensor needs to be interpreted in the light of what other sensors are saying. A more complex matter is that the goal of sensor-data processing may be to deduce a very high-level fact from very low-level signals. For instance, we may want to combine heat, sound, and vibration sensors to locate a person nearby. Sensor networks and the new science will be generating huge datasets. These sensors and datasets will be distributed throughout the world, and can come and go dynamically. This breaks the traditional information integration paradigm, since there is no practical way to apply an extract, transform and load (ETL) tool to each such occurrence.	Data access, standards	Database, DBMS, ETL, query, sensors, sensor network, monitoring	Enhanced query abilities and standards are needed to support rapidly growing sensor networks. Query execution on sensor networks requires a new capacity: the ability to adapt to rapidly changing configurations such as sensors that die or disconnect from the network, and the query plan needs to change as the network changes.
Workshop on the Roadmap for the Revitalization of High-End Computing	2003	Converting requirements into real metrics will allow high-end computing customers to adequately decide what they want and how they know that they have received it. Improved community-standard benchmarks would help streamline and consolidate procurements.	Benchmarks are typically not very effective in disclosing system difficulties that only arise when the entire system is devoted to a single computational job; may need to utilize existing highly parallel systems to perform simulations of current and future high end systems.	Application performance, software assurance, benchmarks	High-end computing, system criteria, benchmarks, application performance	Establish quantitative system criteria sufficient to satisfy future demands for application performance.
Workshop on the Roadmap for the Revitalization of High-End Computing	2003	Employ standard templates for performance analysis that automatically engage typical performance analysis scenarios using advanced tools. High-level tools could also increase the user base of performance facilities by applying techniques of automatic knowledge discovery to performance data.	Further automate and reduce the complexity and cost of modeling work. Define a better interface between traditional tools (such as profilers, timers and hardware performance monitors) and modeling tools.	Performance models, software assurance	High-end computing, performance models	Variety of performance modeling methodologies ranging from simple, curve-fitting approaches to sophisticated tools that perform a thorough inventory of all operations performed by the target application program on a particular system
Workshop on the Roadmap for the Revitalization of High-End Computing	2003	Programming and tuning are significant components of the total time to solution for scientific applications, and reductions in any step will lead to faster overall solution times.	No objective measures exist for the effectiveness or ease of use of tuning tools.	Programming and tuning efficiency	High-end computing, programming efficiency, tuning efficiency, time to solution	Metrics for assessing programming difficulty and ease of tuning to achieve good performance
Assessment Study on Sensors and Automation in the Industries of the Future	2004	Reduction in energy use	Ther are suboptimal measurement and control of processes. The energy metering system (steam and water flow measurements, electric power) is generally very poor, and it is difficult to know the actual energy usage breakdown. Plant information systems seldom reveal much about the actual performance of the energy supply and demand. Need to improve data reconciliation systems and model based performance assessment.	Energy use	Energy metering, energy efficiency, industrial processes, modeling	Uniform metric for predicting energy savings

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Assessment Study on Sensors and Automation in the Industries of the Future	2004	Close the loop on quality by applying advanced sensors and improved real-time control to production lines and control loops, thereby taking advantage of smaller, cheaper and more accurate sensors. If properly processed, the information contained in online process records can be used for predictive modeling of expected product quality as a function of process operating conditions.	Need novel applications of information theory to identify potential relationships among variables, and genetic algorithms for confirming and developing quantitative expressions that can be used for predictive modeling. Sensors currently implemented on production lines cannot measure actual quality of products. Online sensing technology is rather poorly developed to monitor many important quality attributes including taste, feel, texture, smell and other human senses; physical material properties (hardness, corrosion resistance, modulus of elasticity, molecular composition, etc.); and thermodynamic properties, such as thermal conductivity, enthalpy, or other energy content measurements. Many of these measurements are conducted in laboratory environments or by subjective means, so the challenge is to translate these subjective assessments into objective product characteristics.	chemical, physical, mechanical, process variables, thermal, process variables	Product quality, industrial processes, modeling, sensors	Modeling techniques and measurements for product quality using sensors capable of directly measuring product quality
Assessment Study on Sensors and Automation in the Industries of the Future	2004	Obtain ability to operate in a variety of conditions such as extreme environments (high temperatures) and sense data from key locations and application areas. Produce less waste and improved energy efficiency through higher yields.	N/A	N/A	Industrial processes, sensors, energy efficiency	Advanced sensor capabilities that include: sensors for online, real-time, or high speed measurement; sensors for harsh environment applications; analytical and physical property measurements; sensors for non-intrusive or non-contact measurement; sensors for diagnostic and maintenance applications; mixed materials sorting technology; sensors for emission (gas vent flow and composition) and effluent measurements; sensors for microstructure or inclusion measurement; sensors with built-in failure sensing or self-calibration; advanced control techniques; imaging and data communication; modeling and simulation; sampling and process control; and automation
Assessment Study on Sensors and Automation in the Industries of the Future	2004	Automate corrective response.	Need to translate process data into process knowledge and coordinate with control functions.	Process variables	Industrial processes, control functions, automation, manufacturing, sensors	Automated maintenance and diagnostics to identify abnormal situations during manufacturing processes
Modeling & Simulation for Affordable Manufacturing	2003	Develop visualizations that go beyond geometry to faithfully capture underlying physics; model-based systems that support their product and process designs from requirements definition to delivery of productibility; and ability to build predictive models from an understanding of the science basis, including assessment of uncertainty.	Lack of mathematically accurate visualization systems that are compatible with other design systems; need for standardized, automated, model-based performance analysis modules that can be applied to common types of products; subsystem interfaces that are frozen early severely limit the evaluated design space and the options that can be pursued; lack of standards or methods for certifying models and simulations, in which uncertainty is rarely included to any degree of specificity	Visualization, performance, standards, interactions	Models, simulations, standards, manufacturing, interoperability	Metrology to support product design and optimization: visualization/representation; measures and models for product performance, systems integration, and interoperability; standards for validation, certification, and uncertainty

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Modeling & Simulation for Affordable Manufacturing	2003	Create innovation and breakthrough improvements in product performance thorough material models; accurate prediction of part performance during mechanical design analysis; scaleable, comprehensive product life cycle model with enabling architecture and data structures tailorable to all sectors and integrable across all levels of the supply chain; certification of processes or process changes through simulation tools.	Little effort is made to update, enrich, and verify material models based on production results, which limits utility outside their original application. There is no meaningful capability to integrate multiple unit process models into a multi-step tool that can enable early decisions about process options, cost, or optimized utilization of manufacturing assets. There is a lagging role of modeling and simulation tools in the verification and validation of processes.	Geometry, features and attributes, physical states, and other model characteristics, performance, life cycle, materials properties	Models, simulations, material properties/performance, manufacturing	Metrology to support manufacturing processes and materials: materials modeling, life-cycle modeling, unit process prototyping and optimization, process validation and certification
Roadmap for Process Heating Technology	2001	Reliable, affordable, robust, and low-maintenance sensors and control systems will enable more consistent and efficient process heating operations, helping to minimize product variability, reduce energy costs, and boost profitability.	There are few direct process measurement sensors that are low-cost, rugged, accurate, non-intrusive, and easy to use and maintain. There are excessive failures and inaccuracies of thermocouples and other sensors, and there is a lack of smart controls and cost-effective flow control (air/fuel ratio) devices.	Air/fuel ratio, temperature, chemistry, pressure, emissions (NOx, CO, particulates), heat flux, flame/burning properties, flame stability, process variables	Sensors, emissions control, process parameters, process heat, furnace, process industries, process variables, manufacturing	Improved sensors and controls: robust, accurate, non-intrusive, easy to use, low maintenance, reliable sensors and controls that measure multiple emissions, temperature, chemistry, pressure, air/fuel ratio, etc.
Marine and Ocean Industry Technology Roadmap: Thinking Beyond Our Shoreline	2001	Increase safety and efficiency of shipping operations at ports and allow operators to more safely navigate ships into and out of port. The ability to characterize the sea bottoms would help ship captains avoid trouble spots that could lead to accidents, environmental damage, and the interruption of docking/port operations. This could also help develop new automated ship docking systems.	Inability to determine specific gradients and material properties when bringing in large ships to port	Depth, basin gradients, material composition	Sensors, ports, shipping, material characterization, physical sampling, non-contact, remote	Sensors for non-contact characterization of sea port bottoms or physical sampling
Marine and Ocean Industry Technology Roadmap: Thinking Beyond Our Shoreline	2001	New technologies for bathymetric mapping and classification would help in the design and modification of submarine routes and mine installation. Improved radar and sensing technology would assist ocean surveillance and detection and tracking of small objects such as a person in the water.	Insufficient communications technology to achieve desired level of marine security, defense, and emergency/safety operations	Seabed composition, gradients, depth, acousitics, object size, object location, tracking	Sensing, scanners, radar, accoustics, bathymetric mapping, surveillance	Sensing and measurement technology for marine communications: remote radar, underwater acoustics, bathymetric mapping and classification of St. Lawrence beds, side scanners, multi-beam visualization, coherent radar, and sensors on cranes' loading ships
Marine and Ocean Industry Technology Roadmap: Thinking Beyond Our Shoreline	2001	Develop technology to better detect, track, and identify species. Obtain ability to determine local populations or species that are under farmed or not farmed. Obtain capability to measure water quality throughout the growing cycle, and the ability to monitor fish cultures and habitats remotely and transmit that information across vast distances. Employ real-time monitoring techniques for critical conditions affecting the health of finfish or shellfish.	Fish farmers and acquaculturalists lack the sensing and measurement technology to effectively improve the efficiency of current fish husbandry and harvesting operations.	Species identification, habitat characteristics, migration patterns, reproductive patterns, population changes, water quality, fish size	Modeling, sensing, aquaculture, habitat mapping, data analysis, rapid screening, ecosystem modeling, fish capture, seafood, harvesting, marine, satellites, data transmission	Modeling, sensing, and monitoring technology to aid in fish capture, seafood harvesting, and aquaculture; marine ecosystem modeling; habitat mapping; tools and signal processing technology; rapid screening techniques; better environmental sensing and monitoring equipment; computer-based data gathering, storage and analysis; logistics and information technology; satellite technology for remote sensing and communications

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Marine and Ocean Industry Technology Roadmap: Thinking Beyond Our Shoreline	2001	Employ a marine geospatial data infrastructure (MGDI) that will enable remote access to information from multiple sources.	The oceans represent a vast, remote, complex and harsh environment and our understanding of them requires extensive data collection. The data sets that describe this environment can be very large, and combine aspects of both spatial and temporal variability. These data tend to have differing structures, application environments and policies for distribution and use. While some data sets are relatively static (e.g., bathymetry, bottom type), others are dynamic (e.g., waves, surface currents, vessel location), and are often required in "real-time" to be of any value.	Thermal gradients; variations in currents, wave formations, temperature and salinity, energy flows, carbon dioxide levels, tide cycles, fish count, nutrient content, pollution	Data collection, database, marine environment, wave formations, salinity, temperature, thermal gradients, current variation, oceanography, data management, ocean mapping, data acquisition	Improved schemes for the collection and analysis of complex data streams for conditions at and below the level of the seabed and at the sea surface, which would incorporate data from technologies such as visualization analysis; 4 dimensional modeling; ocean process simulation and data fusion; 3D computational modeling of ocean systems with high energy flows (currents, tides, etc.); remote controlled sensors and control systems; deep water mapping including living resources; carbon dioxide sensing; fish counting (acoustically, optically); continuous monitoring of oceanic and atmospheric conditions; measuring and monitoring ocean currents; monitoring the dynamics of deep-water masses; map and survey the seafloor; marine environmental monitoring; and nutrient and pollution measurement (particularly biological and chemical parameters)
Vision 2020 Materials Technology Roadmap	2000	Achieving on-line, continuous, real-time monitoring will significantly improve quality and performance in the manufacturing of new and existing materials. Technicians will be able to optimize process parameters during fabrication, improving first pass quality and yield, and resulting in higher productivity, product quality, profitability, and energy efficiency.	Current techniques to characterize and analyze properties of materials are not suitable for on-line, continuous, real-time applications.	Structure, composition, interfacial properties, aging mechanisms	Materials, composites, polymers, ceramics, sensors, aging mechanisms, manufacturing	Sensors, measurement/imaging techniques in support of materials characterization: development of on-line, spatially resolved, non-contact, robust, highly sensitive measurement techniques for characterizing materials (composition, structure, dynamics for buried interfaces) and their behavior, including aging, tribology, polymer stress cracking, and composites performance during fabrication; development of techniques to analyze multi-component and/or multi-phase materials; development of 3D imaging, chemical information imaging, and mechanical imaging tools
Alumina Technology Roadmap	2001	Increased automation in the refinery will improve process efficiency and productivity as well as reduce manpower requirements. Full automation will reduce process upsets requiring human intervention in potentially dangerous environments, and can also lead to better product quality and consistency.	The alumina industry lags behind the chemical and other industries in its use of process modeling to optimize operations. In addition, most current sensing and automation methods are unable to operate effectively in the harsh, caustic conditions common to alumina refinery environments, impeding implementation of fully automated alumina refining processes.	Product quality, productivity, Bayer process chemistry, temperature, pressure, density, flow, material thickness, material defects, scaling	Alumina, aluminum, metals, automation, benchmarking, instrumentation, sensors, process control, Bayer process, caustic environment, hydrometallurgy, metals, process chemistry, labor	Improved sensors, controls, and instrumentation for use throughout alumina refining process: develop new sensors capable of surviving caustic environments; develop new control software; develop expert systems and neural networks; benchmark process automation and control methods in use by other manufacturing industries; develop better instrumentation to minimize spills; better plant sampling methodologies and techniques; use of new developments in chemometrics; Bayer-specific sensors for particle size, caustic, alumina-to-caustic ratio; in situ techniques that will survive in sodium chemistry; remote sensing (e.g., ultrasonics) to examine material or scale thickness; industry-specific control valves, isolation valves, and pumps for liquor and slurry; at-line instrumentation (simple, robust, real time, operator-controlled); specifications for sensing of common parameters (i.e., temperature, pressure, density, flow) reliably and accurately

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Alumina Technology Roadmap	2001	The development of catalysts for reducing the activation energy for precipitation (as well as other Bayer process steps) could significantly improve productivity. Computer modeling techniques could improve the efficiency of designing such catalysts as well as other additives.	Modeling and simulation techniques to assist the development of new catalysts with improved precipitation properties for use in the Bayer process are inefficient.	Bayer process, precipitation, chemical reactions, crystallization, reagent molecules	Alumina refining, aluminum, metals, precipitation, catalysts, productivity, modeling, software, simulation, Bayer process, chemical reactions	Develop computer modeling techniques for testing new reagents to assist with Bayer process chemical precipitation: simulation of new reagents to promote rapid crystallization; computer modeling of design additives; develop predictive models for the Bayer process
Alumina Technology Roadmap	2001	Better understanding of what is happening along each process step will help refiners optimize operations and increase throughput. A refinery tool for capital process optimization could offer large savings potential through information sharing between companies. An alumina process model could help determine whether certain process steps could be shifted from refineries to smelter operations to reduce overall costs. Models and instrumentation to better model mass balance and monitor refinery releases could reduce caustic consumption, provide opportunities to recover low-grade waste heat from flue gas, and reduce air pollutant emissions, spills, and groundwater contamination.	Better understanding is needed on what is happening throughout each step in the refining process. The industry lacks tailored tools, preventing alumina industry companies from achieving optimal energy, production, and capital efficiency. Cost-effective solutions are also needed to help minimize releases of caustic, organics, trace metals, particulates, and other harmful substances.	Emissions, effluents, solid waste, mass balance, toxicology, water usage, product life cycle, return on investment, capital efficiency, productivity, process variables	Alumina refining, aluminum, capital, life cycle, return on investment, process model, tools, models, process control, emissions, effluents, solid waste, pollution, waste management, environment, best practices, groundwater, metals	New tools and models for process management: model full mass balance to track all pollutant constituents; industrial process model (continuously updated, contains equipment reliability data); capital process optimization tool; life cycle modeling (including environmental factors and cost); process model (including energy and waste data) to define optimal break points; techno-economic model of the Bayer process (validated computational modeling of process steps); full model of plant-wide energy balance
Aluminum Industry Technology Roadmap	2003	Incremental improvements and alternative processes can dramatically reduce energy consumption. Enabling technologies such as sensors, controls, and models are needed to better understand and operate reduction processes at optimal efficiency.	Lack of mathematical models to predict the performance of cell design concepts; inadequate process tools, sensors, and controls for reduction cells	Electrolytic reduction processes, superheat, temperature, bath ratio, process variables	Primary production, cell, anode, cathode, aluminum, alumina, metals, alloys, sensors, controls, models	Metrology to support primary production: revised cell geometry to optimize process; scale-up complexities; models applicable to new cells; continuous or semi-continuous sensors to cost-effectively measure alumina, superheat, temperature, and bath ratio; improved understanding and models of reduction phenomena; rapid scan method to determine metal composition; real-time feed-forward process control
Aluminum Industry Technology Roadmap	2003	Better understanding of the physical phenomena that occur during melting, solidification, and recycling will create a knowledge base for better control of processes, leading to decreased costs and emissions. New technologies and concepts will achieve goals of sustainability, zero-waste, and net positive energy impact. Intelligent online sensors and controls can ensure processes run at optimum productivity and efficiency.	Low efficiency; lack of crosscutting technologies that could eliminate wastes and improve recycling economics; limited understanding of solidification and associated technologies hinders casting and limits return; lack of continuous operation; high contaminant levels; inability to meet OSHA and other standards while using low-grade scrape; outdated specifications; incomplete understanding of explosion triggers	Alloy and metal quality, microstructure, surface properties, stress, and strain; reaction mechanisms; formability characteristics; variation in composition of properties, process variables	Melting, solidification, recycling, reaction mechanisms, aluminum, alumina, metals, alloys, sensors, controls, models, surface interactions, chemical properties, physical properties, manufacturing	Metrology to support melting, solidification, and recycling: fundamental information on solidification of alloys to predict microstructure, surface properties, stress, and strain; integrated process model to predict metal quality; understanding of oxidation mechanisms and surface thermal reaction; techniques to determine formability characteristics and associated test methods; standards and characteristics of melting/casting plant and furnace for the future; real time chemical analysis; sensors to prevent explosions
Aluminum Industry Technology Roadmap	2003	Optimized efficiency and quality can be achieved through better measurement devices. Methods to fabricate products without waste can help improve yields and costs. Research for the consolidation or elimination of processing steps will streamline fabrication for enhanced productivity and energy conservation.	Lack of models to relate structural properties to manufacturing processes and materials employed, lack of accurate material/elemental data by alloy type, lack of surface chemistry information, inadequate measurement methods for process control	Chemical composition, strength, formability, microstructure, dimensions, texture, speed, temperature, pressure, residual stress	Aluminum, alumina, metals, alloys, sensors, controls, models, surface interactions, chemical properties, physical properties, characterization, manufacturing	Metrology to support fabrication: integrated models that relate structural properties to manufacturing processes and the materials employed; new/improved non-contact sensors; understand factors affecting metal flow in hollow extrusions; understand relative strength and formability of alloys as a function of thermomechanical processing and chemical composition; understand alloy behavior, which includes crystallographic texture changes during thermomechanical processing

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Aluminum Industry Technology Roadmap	2003	Greater understanding and numerical methods provides a base for optimum designs, including larger structural analysis base and variety design of alloys for applications. This can lead to advanced materials selection, increased productivity, new products/markets, and decreased costs, energy consumption, and lead times.	Lack of integration between process and product design; inadequate computer design and simulation tools to link product design and optimized manufacturing; limited understanding of relationships between microstructure and material performance; inadequate process control technology	Physical properties, chemical properties, microstructure, alloy and metal quality; material/process/pr oduct design, process variables	Aluminum; alumina; metals; alloys; sensors; controls; models; chemical properties; physical properties	Metrology to support alloy development and finished products - understand relationship of alloy composition and processing and effects on microstructure and properties (including nano-structures) for next generation aluminum alloys; tools for alloy design with improved physical properties; integrated numerical methods for analysis and robust design of products, processes, and material; simulations of finished product fabrication processes; online, real-time sensing for process control
Applications for Advanced Ceramics in Aluminum Production	2001	The operation of the electrolytic cell can be improved through better monitoring and control of key chemical and physical parameters. Possible technologies include a tube composed of an advanced ceramic material to serve as a protective shield for existing sensors (such as those measuring temperatures of the cryolite-aluminum bath) and new ceramic-based sensors capable of measuring the alumina content of the bath, allowing tighter control of bath chemistry and thus reducing harmful "anode effects," among other benefits. New sensors could be developed composed of silicon nitrides, boron nitrides, diamond, or other coatings. In the longer term, these sensors would be thermally shock resistant, enable accurate temperature measurement, accurate content measurement within 0.2% actual content, and capable of continuous three to four week duty. Such sensors	Many current sensors are incapable of operating continuously in the harsh environment characteristic of a molten aluminum/molten cryolite bath for a full carbon anode lifetime (approximately three to four weeks). Sensors of sufficient chemical and heat resistance are lacking.	Thermal shock resistance, heat resistance, chemical/corrosion resistance, durability, measurement accuracy (content and temperature)	Aluminum, sensors, smelting, process control, ceramics, anode, cryolite, electrolyte, corrosion	Robust sensors for use during aluminum smelting operations: thermocouple protection tubes that can be immersed in molten aluminum to allow continuous temperature measurement, sensors for measuring Al2O3 content of molten electrolyte, sensor protection tubes
Applications for Advanced Ceramics in Aluminum Production	2001	A uniform performance measurement system encompassing the entire aluminum production process will establish a baseline to justify material change. With better proof of performance enhancements provided by new materials technology, aluminum producers will be more willing to adopt novel materials technology into their standard operations, in turn helping to advance production efficiency and product. Such measurements could also lend themselves to new simulation and standardized testing techniques, reducing both the potentially high costs and risks common to developing and implementing new materials technology. Gathered data could be used to create an actively updated materials catalog/database containing useful information on material performance relative to specific aluminum parameters.	Without consistent measurement methodologies and criteria in place, aluminum producers find it difficult to benchmark sensor performance and accurately determine the costs/benefits of new material applications in furnaces and other equipment.	Corrosion resistance, heat resistance, thermal shock resistance, cost/benefit, material life cycle	Aluminum, furnace, ceramics, measurement system, baseline, benchmarking, simulation, testing, materials of construction	Develop baseline measurement system to determine cost/benefit of new material applications in manufacturing equipment, and enable standardized testing of new product applications.

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Applications for Advanced Ceramics in Aluminum Production	2001	Sensors that can more accurately measure temperature in aluminum furnaces would improve product quality and production efficiency. The development of advanced ceramic sensors for furnace operations could lead to new optical sensors for measuring molten metal temperature; sensors for inclusion detection, oxygen detection, and salt detection; and refractory particle detection via contacting probe with molten aluminum.	Existing thermocouple tubes are incapable of sufficiently withstanding the harsh environment within aluminum furnaces. As such, aluminum producers are incapable of monitoring temperature in the aluminum bath directly. New sensor materials are needed that are more resistant to thermal shock, corrosion, and high temperatures. Current oxygen sensors that monitor rich/lean atmospheric qualities to not work well to control quality. Traditional coated cast iron sensors are far more inexpensive to produce than those composed of advanced ceramic materials. Common in-roof thermocouples composed of aluminum silicon carbide to control roof temperatures cannot measure bath temperature.	Corrosive resistance, erosive resistance, thermal shock resistance, heat resistance, measurement accuracy, sensor life cycle	Aluminum, furnace, sensors, process control, ceramics, product quality	Sensors for process control via accurate temperature measurement for furnace and molten metal handling operations during aluminum production
Forging Industry Technology Roadmap	2002	Develop real-time, non-destructive measurement systems. Develop techniques to measure exact loading of die press. Understand and measure the effect of design and process variables on the forging to achieve "first piece - good piece" techniques. Develop non-destructive measurement techniques of the real-time temperature profile of the billet during induction heating.	Real-time, non-destructive testing; lack of use of passive sensors; limit forging load; need for cost-effective process monitoring; accurate, non-contact dimensional measurement; consistent bar billet temperature; do not know when the die is dead; accumulating forging process data for evaluation	Process variables	Forging, die, tooling, sensors, temperature control, billet, aluminum, steel, NDE	Develop real-time, non-destructive measurement systems for the forging industry.
Forging Industry Technology Roadmap	2002	Reach development of hot dimensional measuring capabilities for taking real-time measurements of forgings during the deformation process.	Lack of ways to measure dimensions of hot objects	Physical	Forging, die, quality, productivity, sensors, temperature control, billet, aluminum, steel	Develop real-time, hot-dimensional measuring capabilities
Forging Industry Technology Roadmap	2002	As an essential components of smart forging presses, develop robust, high-temperature sensors that can accurately measure process parameters such as vibration, acoustics and strain.	Lack of advanced, high-temperature sensors capable of measuring vibration, acoustics, and strain	Acoustic, mechanical, thermal	Temperature, vibration, sensors, strain, forging	Develop advanced sensors to measure high-temperatures, vibration, acoustics, and strain. Develop vibratory signature analysis equipment especially designed for use by the forging industry
Metal Casting Industry Technology Roadmap	2003	Material property data on cast alloys that reflect the process capability to meet form, fit, and function would greatly enhance the selection of casting as a preferred method for producing engineering components along with forging and joining mill products.	Lack of material property data to meet specific performance criteria and account for molten alloy castability characteristics, the interface heat transfer coefficient with various molding processes, and final solidified material properties	Fatigue behavior of cast ferrous and nonferrous alloys, toughness, stiffness, creep, patternmaker's contraction factors, porosity, nonmetallic inclusions, microstructure, data	Metalcasting, metals, cast alloys, material properties, mechanical properties	Material property data for improved metalcasting design: develop wrought equivalency data; bulk mechanical and physical property data for cast alloys; characterization of the fatigue behavior of cast alloys and correlate with parameters used in design software; develop solidification feature threshold/standards
Metal Casting Industry Technology Roadmap	2003	The proper combination of geometry, alloy, and casting processes can make "difficult-to-cast-alloys" economical to cast, with reduced variability in material properties. Greater understanding of governing relationships will have beneficial crosscutting effects in casting applications as well as in quality and consistency of production.	Not all dimensions in an engineered component can achieve the required dimensional tolerance, and cast components may not perfectly conform to the dimensions of the pattern or die cavity from which they are produced. This difference occurs because of processing variables and variations in the heat transfer at the mold/metal interface with 3-D model cavities.	Microstructure, substructure, and residual stress on machinability; benchmark sensitivity of process variability, thermophysical data, heat transfer, pressure, tolerance, standards, data	Characterization tools, metalcasting process, material properties, mechanical properties	Metrology to support design process interrelationship: Refined sand model/improved understanding of low-expansion sand; quantify effects of microstructure and residual stress on machinability; development of simulation tools to predict casting properties; methodology for predicting casting performance before casting is produced; thermophysical modeling data; mechanical properties of pressure during solidification; models of solidification process inside a mold or die; NDE standards; expand dimensional tolerance system through casting design

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Metal Casting Industry Technology Roadmap	2003	Improved design competitiveness will assist metalcasters to cut costs by reducing or even eliminating costly finishing operations. Tools are needed so casting models with geometric rules for each casting process are embedded in computer aided design software. These rules assure the design for manufacturing principals is rooted in the preliminary design.	Design engineers generally lack understanding of the capabilities and properties of castings. This limited casting process knowledge hinders the industry's ability to add value during the design phase, where inputs are key to reducing costs and errors. Metalcasters need to become full-service providers by designing the casting as well as producing it.	Solid models, solid geometry, stress/strain values, material and process alternatives, material properties, process parameters	Characterization tools, material properties, process parameters, metalcasting, design	Characterization tools to enhance design competitiveness: software for bi-directional associativity between meshes and solid geometry; integrated design modeling tool to show the relationship between material properties, the specific casting process, process parameters, and the influence on the final cast product; parametric design capabilities to change one parameter and cause the entire model to adjust accordingly; model and volume-driven tooling; materials/process software selection program for exploration of material and process alternatives
Metal Casting Industry Technology Roadmap	2003	Establish ability to quantify the effect of variability factors on yield and efficiency, prioritize them, and implement measures to reduce or eliminate their occurrences.	Casting variability, along with difficulty in understanding and predicting the factors that cause it, results in unacceptable scrap levels, reduces casting yields, slows the production process, affects scheduling, increases post-cast requirements, and inflates in-process castings and inventories.	Microstructure, casting variables (hydrogen levels, mold temperature, molten metal quality)	Metalcasting, variability, standards	Metrology to support the reduction of casting variability: establish standards defining casting quality acceptance criteria; smart technologies/real time variability measurement devices (gases, sand, temperature, etc.); heat treating optimization; standards for fluidity tests; analyze effects of trace element contamination on variability; understand mold cavity filling surface area-to-volume ratio; analyze role of gravity during solidification; understand element partitioning; characterize molding media properties and how they change with temperature; interrelationship between microstructure, casting process, and product performance
Metal Casting Industry Technology Roadmap	2003	Assure consistent quality, reduce scrap rates, better control production and proper combination of charge materials, minimize unacceptable discontinuities, reduce energy requirements, and improve energy efficiencies.	The harsh environment within the mold requires a combination of advanced, high-temperature sensors that can withstand the conditions for validation of numerical simulation tools. There is consumer demand for lightweight, efficient components. A barrier is excess energy usage.	Physical properties, efficiency, thermophysical data, process conditions	Characterization tools, material properties, energy, efficiency, metalcasting process	Metrology to support innovative and intelligent processing: simulation and modeling tools; durable and reliable sensors; evaluation of thin-wall casting; improved off-gas analysis; flask size optimization; optimize die surface architecture; optimize energy use and melting quality
PM2 Industry Powder Metallurgy and Particulate Materials Vision and Technology Roadmap	2001	A thorough understanding of particulate material science will help the powder metals industry achieve exceptional part performance through enhanced material properties. Innovative materials will enable market expansion via expanding the portfolio of material options powder metals and powder materials that companies can offer their customers. Better understanding the behavior of composite materials will help ensure that the advantages of the powder metallurgy process are fully realized in part via the ability to manufacture particulate composites at high volumes in a more cost-effective manner. Improving powder processing will enable materials to be produced more quickly and accurately while reducing cost and improving efficiency.	Insufficient knowledge of porosity-property relationships; incomplete knowledge of relationships between material phases/constituents, properties, and performance; inconsistent understanding of material science (in its application to particulate materials) throughout the industry; shortage of thermophysical data, specifically for new materials; resistance to the qualification of new materials and processes due to lack of standards and materials property data; difficulties controlling critical power characteristics (e.g., surface contamination, size distribution, etc.) during powder production; inability to process, handle, and monitor fine powders; and lack of standards for blending fine powders. The lack of methods to measure critical variables inhibits greater part uniformity. Basic studies to understand long-term behavior and consistency of parts from a given batch of raw materials would help minimize process interruptions to move toward more continuous production of higher quality materials.	Porosity, surface contamination, size distribution, thermophysical properties, material interaction, particle structure, composite structure, part density, particle reactions, compaction, elastic modulus, magnetic properties, metal-powder interface, creep	Powder metals, particulate materials, porosity-property relationship, materials science, powder processing, composite materials	Fundamental characterization studies for new materials (determine property-structure-performance relationships) and develop improved understanding of existing powder metals and powder processing techniques; assessment of powder measurement techniques; understanding of process-microstructure-performance relationships; research material properties between 90 percent and full density; thermophysical data development; proper data for lightweight materials (metal matrix composites); fundamental porosity-property studies; biomedical materials research; study compatibility of functionally gradient materials; ability to predict properties from microstructure; understand new materials properties; research particle reactions, intense atomization processes for droplet control (in situ composites with tolerance control); methods to measure critical variables such as density; long-term behavior and consistency of a part produced from a given batch; correlation

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PM2 Industry Powder Metallurgy and Particulate Materials Vision and Technology Roadmap	2001	Modeling of parts and processes are fundamental to development of more sophisticated and reliable processing techniques and would allow process optimization through both off- and on-line simulation. In combination with non-destructive evaluation diagnostics, developing new sensor and control technologies while exploring innovative uses for current sensor and control mechanisms will help cultivate a more complete understanding of basic process phenomena to reduce process inefficiencies, defects, and variations. Testing facilities would help to gather such data, accelerating technology deployment throughout the industry.	Inadequate material and process modeling capability; inability to measure internal cracks in green parts online; limited process and product control methods; lack of accelerated testing and long-term testing data; limited understanding of critical parameters to monitor and interrelationships for quality; and lack of an integrated database to assist designers in achieving desired performance characteristics	Particle size, particle distribution, flow rates, press conditions, furnace conditions, density, strength, fatigue, toughness, wear, gas composition and volume, temperature, internal cracks, uniformity	Sensors, controls; design tools; non-destructive evaluation; modeling; simulation; powders; powder metals; powder materials; sintering, pressing, testing and demonstration; powder processing; manufacturing	Improved sensors, controls, modeling techniques, and diagnostic tools; material and process modeling capabilities for pressing, sintering, gas flow in furnaces; etc.; in situ sensors for closed-loop controls and quality assurance; sensors to optimize gas supply systems and gas use during sintering; efficient temperature control for both process heat removal and addition; fundamental phase equilibrium and other data for powder and product design; user-friendly mathematical models to assist in process optimization; system-based, closed-loop feedback controls; Internet-based design advisor; agile PM testing facility for gathering data; enhanced control over powder uniformity; advanced controls for more accurate green compacting and sintering; low-cost diagnostics techniques to rapidly evaluate critical performance characteristics of powder and green components; non-intrusive, stable sensor materials for process control; demonstration test bed for integration of process models; sensors, and non-destructive
Steel Industry Technology Roadmap	2001	Modern distributed control systems incorporating the online data in conventional byproduct plants or syngas-producing plants; greater energy efficiency, higher productivity cokemaking, reduced waste	Inability to determine optimal process sequencing for highest energy efficiency and lowest cost coke production	Coke and ore fines; fuel content; byproducts (gas, tar, oil, waste oxides, etc.); fuel content, temperature, carbon levels, air levels	Steelmaking, cokemaking, process control, distributed control, process optimization, data collection	Online data collection for cokemaking operations
Steel Industry Technology Roadmap	2001	Develop low-cost sensors and a comprehensive blast furnace model that steelmakers could use to optimize in-plant coke oven and blast furnace off-gas utilization, as well as evaluate recent tuyere injection developments. Improve productivity and energy efficiency of direct reduction of iron ore, iron smelting, and blast furnace operation. Define new opportunities to combine electric arc furnace and submerged arc furnace technologies into unique smelting furnace.	Technology developments have outpaced modeling capabilities. There is no comprehensive blast furnace model (including fluid flow and kinetics) or accompanying lower-cost sensors. Engineering problems are associated with the design of fluid-bed processes. There is a limited understanding of rate controlling steps and optimization of process variables in direct reduction.	Fluid flow, kinetics, gas composition, temperature, bed permeability, char control, foaming, metal dusting, rate of reduction, carburization, pressure	Steelmaking, ironmaking, sensors, blast furnace, process model, fluid flow, kinetics, direct reduction, iron smelting	Sensors and process models for ironmaking processes: comprehensive model of blast furnace; low-cost sensors to measure gas composition, temperature, and bed permeability; determining rate-controlling step and the effect of operating variables on the rate of reduction and carburization relevant to fluid-bed processes in direct reduction; fluid flow and kinetics in fluid-bed reactors; measuring phenomena of metal dusting in direct reduction; control models for reduction, char control, foaming, and post combustion/heat transfer for smelting systems

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Steel Industry Technology Roadmap	2001	Achieve more energy efficient, higher output steelmaking processes and technology with reduced waste.	Inability to measure number of steelmaking process variables within BOF and EAF operations	Heat, temperature, pressure, slag composition, lance-to-steel bath distance, slopping, waste gas composition, furnace shell temperatures, bath carbon, dusty bin levels, turndown metal content, section size, melt carbon time, scrap temp, process variables	Steelmaking, basic oxygen furnace, electric arc furnace, sensors	User-friendly, robust process sensors and modeling tools for steelmaking to measure process variables: sensors with feedback capability to detect bath carbon, temperature, advent of slopping, waste gas composition, dusty bin levels, and furnace shell temperatures; temperature sensors able to measure continuously during final minutes of the BOF blow; sensors for quick analysis of turndown manganese, sulfur, and other elements; robust sensors to detect lance-to-steel bath distance; improved laser scanning system to characterize condition of furnace and ladles; inexpensive and fast slag sample preparation and composition analyzer; comparison of process parameters vs. results of models for fluxing and oxygen blowing; predictive maintenance procedures for drive bearings; instant steel bath and off-gas chemistry and volume analysis to enable feedback control; artificial intelligence techniques for electric arc furnaces (EAFs); real-time offgas analysis method for EAFs
Steel Industry Technology Roadmap	2001	Achieve higher productivity ladling processes via minimization of sampling and analysis time, allowing ladle refining and component processing to be executed in parallel.	Affordable systems are needed to enable concurrent processing and eliminate unproductive time.	Steel chemistry, steel temperature, slag chemistry, slag temperature, inclusion mass, size distribution, heat transfer, mass transfer, inclusion content, process variables	Steelmaking, ladle refining, sensors and control, process modeling, heat transfer, mass transfer	Sensors and control systems for ladle refining operations: rapid or continuously operating sensors for steel and slag chemistry and temperature, as well as inclusion mass and size distribution determination; techniques for stream temperature prediction and control; coupled heat and mass transfer models to allow prediction of effect of ladle metallurgy on chemistry and inclusion control; rapid chemical sensors; laser-based immersion probe system for elemental analysis within a minute
Steel Industry Technology Roadmap	2001	Develop higher quality steel castings. Alternative processing strategies could achieve specific measurable properties. Eliminate defects during casting, and improve productivity and product consistency. Achieve the ability to predict and control the exact geometric profile of a casting. Obtain automatic online monitoring of cast processes, and allow design of new alloys to achieve specific properties. Also, allow the thermal conditions in the growing shell and in the rotating shell to be defined and enable in situ compensation or correction for roll distortions.	Insufficient process control capabilities in steel casting operations limit advances in process performance and cast product quality.	Inclusion content, temperature, fluid flow, oxidization, inclusion distribution, fluid chemistry, stability, bubble distribution, slag emulsification, heat transfer, cast shape, cast structure, cast solidification, process variables	Steel, casting, sensors, process control, modeling	Sensors and modeling tools for steel casting processes: modeling of interaction of fluid flow at slag-metal interface; database of stability diagrams for all grades of steel (and techniques to calculate stability); ability to monitor and actively control fluid flow, temperature, and chemistry; sensors that employ wireless technology to communicate data and diagnostic information; vision systems for defect detection and identification; sensors for cast shape, inclusion or bubble distribution, and structure; advanced heat transfer and fluid flow models that include free surface of liquid/liquid boundaries, prediction of slag emulsification, final position and shape of cast surface, and detailed prediction of cast structure, inclusion, or bubble distribution and segregation patterns; technology to measure interactions between steel shell, the flux, and interface of the mold; comprehensive heat transfer, fluid flow, and solidification models; understanding of SO_2 formation during ladle refining process

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Steel Industry Technology Roadmap	2001	Develop process control equipment to support customer driven menus, accurate and repeatable drive systems for tension free rolling, interstand cooling, and reduced roll and pass changes for equipment. The end result is modular equipment capable of higher speed operations with increased production rates due to reduced downtime. Product consistency will also increase. Material property, thermodynamics, and kinetics data can be used to help develop new alloys and surface coatings for use in specialized applications.	Current sensing and characterization technology is sometimes destroyed during steel processing at these stages (heating, rolling, shearing, parting, heat treatment); characterization technology in use may be incapable of determining critical process variables fast enough to keep pace with rapid mill start-ups, quick changeover times, precision sizing, and colder rolling capabilities anticipated as the growing trend in future steel rolling and finishing operations	Thermodynamics, kinetics, gradient cooling rate, point-to-point composition variations, stress, fatigue, dissolved carbon, dissolved nitrogen, wear-resistance, microstructure, material transformation, temper rolling strain, interstitial solute content	Steel, rolling operations, finishing operations, metal surface coatings, sensors, non-destructive evaluation, heat treatment models	Characterization of steel rolling and finishing process variables: characterization of thermodynamics and kinetics of phase transformation under stress and influence on transformation and microstructure evolution; application of techniques such as internal friction to measure the dissolved carbon and nitrogen in alloys; material property characterization of new coatings; closed-loop control of heat treatment processes via feedback from suitable microstructure sensors; robust hot steel identification technology; online, non-destructive evaluation technology to measure mechanical properties and surface appearance; in-line direct detection and classification of surface defects in hot and cold rolling operations
Steel Industry Technology Roadmap	2001	Improve design of steelmaking vessels; incorporate reclaimed materials into a variety of products; and improve high alumina, basic, and carbon/graphite-containing castables leading to reduced steel manufacturing costs.	Enclosure of submerged entry nozzles (SENs) makes it difficult to determine accretion formation mechanisms and the effects that practice or refractory changes make on the clogging or wear phenomena of SENs. High temperature, corrosive environments are hard on sensing technology. The wide variety of refractories coupled with the myriad operating conditions makes it exceedingly difficult to fully characterize spent refractory materials.	Accretion formation; dewatering rates; contact angle; finite element thermal analysis; flow modeling; metallurgical properties (stress, strain, thermal resistance, fatigue, corrosion); refractory chemical/physical properties; surface cracks; temperature	Steel, steelmaking, refractory, submerged entry nozzles, dewatering, high-temperature, sensors, castable refractories, refractory recycling, refractory reclamation	Steel refractory sensing and modeling tools: detailed post-mortem microstructural analysis and clog characterization; simulation of clogging of the nozzle interior; flow modeling and finite element thermal analysis combined into a new model to predict clog locations and rate of accretion; systematic investigation of molten steel sessile drop contact angle on flat substrates of single phase components of typical nozzle materials; field simulations for side-by-side performance and post-mortem comparisons of standard and improved nozzle designs; laboratory scale furnaces that accurately simulate single-sided heating of a castable refractory lining (dewatering simulations); measurement of castable lining properties during dewatering (e.g., strength, elasticity, permeability); modification of existing dewatering models to incorporate data from dewatering rate studies; corrosion testing and post-mortem characterization of slag line castable refractories and slag line bricks; field trials to measure performance of castable
Steel Industry Technology Roadmap	2001	Achieve lighter gauge container products; electromagnetic brake mold devices; production of wider material at increased capacity; advanced automation of container manufacturing processes; real-time process monitoring technology; new can- and end-forming processes; and improved container performance, including reduced material consumption, increased axial strength, increased paneling resistance, increased buckling strength, increased dent resistance, and increased external rust resistance.	Current casting and filtration technology is not available to achieve target sub-4-ten-thousandths of an inch inclusion size deemed necessary to minimize canmaking failure. There is insufficient capability for in-line measurement of coating thickness. Creasing, buckling, and shape problems become more problematic as gauge size is reduced, so the need is for quicker, more accurate detection than some current technology allows.	Axial strength; gauge; inclusion detection; paneling resistance; corrosive resistance; chemical composition; thermal wear; surface defects; mechanical properties (stress, fatigue, etc.); process variables; quality	Steel, container, tin-milled product, container surface coatings	Analysis of steel container manufacturing techniques and process variables: assess sensitivity of modern steels to tin residual levels; detection systems to identify location of inclusions; automated in-line detection systems with effective discrimination; assessment of process/property interactions in light gauge tin-milled product (TMP) containers

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Steel Industry Technology Roadmap	2001	Achieve new high-performance steels for construction applications, less costly construction steel manufacturing processes, weight reduction in automobiles, and improved crash performance of steel used in autos.	Specific guidelines for steel thickness, yield strength, ductility, and coating thickness do not exists in construction field for secondary processes such as roll-forming (cold reduction through the radii). Some new fabrication techniques are not fully developed. Upper shelf toughness values as measured by a Charpy impact test are often in excess of 200 to 250 ft-lbs., which is well beyond validity of the test method. The traditional fracture prevention methodologies based on Charpy impact test results are being challenged. There is a lack of standardization of methods to determine optimum weld locations and predict weld-line movement for non-linear welds in auto steel; a lack of alternative assembly joining technologies for auto steel; and restricted access to database of impact and torsional performances of a range of components manufactured from a variety of steels and joint designs for autos.	Yield strength, thermal characteristics, crack detection, corrosive resistance, load, fracture propagation/arrest, fatigue, stress, strain, thermal conductivity, elastic modulus, plate thickness, gauge, thermal resistance, inclusion detection, ductility	Steel, steel construction, automotive steel, process control, manufacturing process modeling, manufacturing, structural materials, database	Analysis of steels used in construction and automobile applications: determination of allowable limits and placement of those limits on bending and forming of low ductility steel; occurrence and extent of micro-fissures through curved formed portion or radii created by high-speed roll-forming; measuring practices of thermal effects of steel; determination of corrosion-protective expectation of marginal (low-cost) coatings and measurement of the long-term corrosion effects on construction steel coatings; diaphragm load testing and analysis; comprehensive database and modeling techniques for plate finishing; fracture propagation/arrest models for high-operating pressure pipelines; understanding of fatigue of welded joints; update input data for computer simulations of formability, structural integrity, and crash worthiness of auto steels; database of impact and torsional performance of auto components; more accurate information on mechanical properties (full stress-
Welding Technology Roadmap	2000	N/A	N/A	Physical	Weld dimensions, flaw dimensions, quality control	Improved dimension measuring and evaluation of current measuring technologies
Welding Technology Roadmap	2000	Real time sensing technologies will eliminate or lessen the need for offline destructive tests for weld quality control, allowing greater productivity through in-line sensors and greater weld reliability through more complete quality control.	Sensing weld defects traditionally rely on destructive tests of offline, random samples. Introducing sensory equipment to the weld process must accomplish detection non-destructively and in real time.	Defects, quality	Real time quality control	Real time defect sensing technologies
Welding Technology Roadmap	2000	Improved inspection of weld seams on aircraft for quality and reliability, with great safety margins.	N/A	Welds, physical, mechanical	Laser tracking systems, laser monitoring, sensors, manufacturing	User-friendly, laser-based seam tracking systems
Welding Technology Roadmap	2000	N/A	N/A	Quality control standards for specific weld applications	Performance targets, performance metrics, quality control	Measurement of performance targets for particular applications
Welding Technology Roadmap	2000	Knowledge management systems will merge welding requirements and welding knowledge in industry-accessible databases to support integrated welding across the entire manufacturing cycle.	N/A	Physical, weld integrity, materials properites	Best practices, knowledge management, data	Knowledge management system for welding techniques and manufacturing system techniques for heavy industry
Welding Technology Roadmap	2000	N/A	N/A	Process control statistics	Statistical process control	New generation of statistical process control for weld processing applications
Welding Technology Roadmap	2000	N/A	N/A	Material non-uniformities, material characteristics, physical and chemical properties, grain size, porosity, inclusions	Material properties, integrity standards	Development of relationships between material anomalies and physical and chemical properties (e.g., grain size, porosity, inclusions) for use in realistic integrity standards
Welding Technology Roadmap	2000	N/A	N/A	Thermal fatigue	Fitness-for-service, welding tools	Fitness-for-service and weldability data (e.g., thermal fatigue) to use in tools

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
Welding Technology Roadmap	2000	Industry-accessible engineering database should contain data on the properties and characteristics of welding materials and welds, with a history of past solutions. Wide availability of materials data and established procedures will help designers and welders compare material and manufacturing processes, and select the best options for their particular application.	N/A	Physical, mechanical	Database, welding properties	Welding solution database that contains particulars rather than ranges
Welding Technology Roadmap	2000	Supports quality and reliability of performanc eof welds in heavy industrial equipment.	N/A	Fitness-for-service	Fitness-for-service, manufacturing	Standards based on fitness-for-service
Welding Technology Roadmap	2000	N/A	N/A	Heat input, metal melted	Laser, process monitoring	Evaluation of laser technologies for process monitoring (e.g., heat input, metal melted) for construction/heavy industry
Welding Technology Roadmap	2000	N/A	N/A	Standards, protocols	Weld quality	Design guidelines for details, constructability, economical fabrication (details) emphasis for both designer and fabricator
Welding Technology Roadmap	2000	Designers and welding engineers will be able to relate weld microstructure and related properties to specific welding processes. These techniques will reduce production lead times while ensuring weld quality. Combining data on materials characteristics with information derived from past failures will improve the design of welded products. These data can also be incorporated into model-based process control tools that will facilitate selection of optimal process conditions through increased understanding of the welding process. The benefits will include the ability to weld materials previously not used, increase the knowledge base, better quality and lower costs, and reduced energy use.	N/A	N/A	Simulation	Concurrent product/process simulation and development
Welding Technology Roadmap	2000	Economical reliable inspection technologies that do not constrain product design, fabrication, and process flow could help ensure the quality of welded structures without increasing delivery time or final cost. Welding and inspection of those welds will likely be integrated into one operation.	N/A	Welding conditions, quality	In situ, manufacturing	In situ recording of welding conditions in real time
Welding Technology Roadmap	2000	It validates original processing, and determines fitness-for-service.	Current weld assessment procedures require destruction of samples.	Physical	Embedded sensors, intelligent sensors, non-destructive	Material-based (embedded sensors/intelligent elements), non-destructive evaluation of welds
Welding Technology Roadmap	2000	N/A	N/A	Material microstructure, heat treatment requirements	Heat treatment, microstructure	Longer term, more focused understanding of post-weld heat treatment requirements (e.g., microstructure)
Welding Technology Roadmap	2000	N/A	N/A	Weld strength, durability, corrosion	Quality control, non-destructive, evaluation	Research on extended weld life assessment, including non-destructive but field-applicable evaluation

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Welding Technology Roadmap	2000	Welding simulation capabilities integrated with system models can compress the time needed between the design phase and production start-up. The capability to simulate thermal, mechanical, and metallurgical changes caused by welding and to predict distortion and residual stress will help product development teams select the best welding option and better predict weld lifetime and performance. Benefits include reduced production costs, reduced reworking requirements, otherwise improved weld quality, lower energy consumption, and market growth.	N/A	Fundamental data on high temperature materials, weld metallurgy, relationships between material anomalies and material properties.	Mathematic, modeling, simulation, welding, manufacturing	More comprehensive mathematic/scientific understanding and modeling of welding
Welding Technology Roadmap	2000	N/A	N/A	N/A	Predict, statistics, quality control, residual stress	Capability to predict distortion and understand effect of residual stresses
Welding Technology Roadmap	2000	N/A	N/A	Human hand mechanics and movement	Modeling, human-machine, anthropomorphic control	Study of welders' hand motions as basis for computer models/machine controls
Welding Technology Roadmap	2000	Innovation in weld imaging based on the use of transient thermal or electrical energy, similar to the MRI technique used in medicine, could significantly improve weld quality, particularly in more critical applications. Productivity could also be enhanced as false indications are reduced. The development of this type of imaging tool may allow the use of new materials in welded applications.	N/A	Physical	Imaging, 3-D, three dimensional, defect detection, defect sensor	3-D imaging technology that captures all observable defects in welds
Welding Technology Roadmap	2000	Such models will enable designers to predict weld/bond integrity and performance based on historical weld quality data.	In-process data acquisition is an existing technology. However, automakers must use more sophisticated, non-destructive methods for evaluating weld integrity versus the currently used chisel-and-pry test or destructive testing on a sampling basis.	N/A	Model, simulation, predict, statistics	Models that accurately predict weld joint performance
Welding Technology Roadmap	2000	N/A	N/A	Metallurgical, thermal, mechanical effects of welding	Model, simulate, predict, metallurgical, thermal, mechanical	Capability to accurately predict changes due to thermal, mechanical, and metallurgical effects of welding
Welding Technology Roadmap	2000	N/A	Inspection processes must be capable of examining a variety of materials without requiring high operator skill level. Inspections should be effective on both arc and resistance welds. Welds on high-strength steels and non-ferrous alloys cannot be reliably tested using the current chisel-and-pry testing method. New non-destructive evaluations must be easily integrated and cost-effective and must accommodate low-level operator skills.	Physical	Evaluation, sensor, quality control, inspection	Economic, robust non-destructive weld inspection processes for automotive, high-volume applications
Center for Advanced Separation Technologies Technology Roadmap	2003	Optimization of solid-solid and solid-liquid separation will provide greater efficiency and productivity. New controls and sensors can be low cost, low maintenance, user-friendly, and benefit employee safety and health.	Inadequate efficiency and productivity levels, extraction of waste rock, inability to measure reduction oxidation	Particle size, differentiation of particles/sorting, efficiency of classifiers and separators	Particles, minerals, sensors, controls, spectroscopy, efficiency	Improved measurement systems and control (sensors): optical sorting; independent, online, real time device/performance control/measurement; online particle size analysis, washability, mineral liberation; in situ spectroscopy and interaction force measurements

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Center for Advanced Separation Technologies Technology Roadmap	2003	Models can predict methods of improving flotation processes through the development of simulators. Permeability, recovery rate, and productivity of heap leaching practices can all be improved through particle property characterization. Emission and waste control can also be improved through characterization of species through their life cycle from deposit to processing to waste disposal/recycling.	Limited understanding of the flotation rate process, lack of new heap leach technologies, lack of ability to predict profile of refuse streams, creating coal impoundments	Surface properties, chemical properties, composition, permeability, unsaturated flow, scale-up, bubble-size, energy dissipation, surface chemistry	Particles, minerals, characterization, modeling	Tools for characterization and modeling: flotation modeling, hydrodynamic and thermodynamic modeling for leaching, particle characterization
Education Roadmap for Mining Professionals	2002					
Exploration and Mining Technologies Roadmap	2002	The ability to define the location and quality of mineral resources, with a high degree of confidence, can dramatically improve the economics and energy efficiency of mining. Technologies in imaging and sensors can be used to replace certain tasks such as drilling to characterize an area without disturbing the environment.	There is a need for better sensing and imaging technologies for mining applications that have not been developed yet.	Geological, chemical, physical	Mining, exploration, imaging, underground, sensors	Measurement sensors and imaging technologies are needed. Develop ways to sense, visualize, interpolate, model, and predict anomalies in front of mining equipment. Also, develop geological sensing devices to monitor and evaluate material ahead of the working face. Remote sensing technology: real-time, >1000' deep, horizon sensing, projectiles that can transmit underground geological information, accurate laser analytical technologies, sensors for underwater explorations
Mineral Processing Technology Roadmap	2000	Improved sensors, controls, and instrumentation could enable better characterization of mineral inputs and process automation, leading to optimized mineral processing activities (blasting, drilling, crushing, etc.) and reduced energy and processing costs.	Lack of sensors, controls, and instrumentation for inline, real-time characterization of minerals and process automation	Ore type, oxide content	Minerals, sensors	Improved sensors and controls for inline, real-time characterization of minerals and process automation
Mining Crosscutting Technologies Roadmap	2000	Improved sensing and imaging methods will reduce the amount of drilling necessary to accurately characterize a reserve or ore body, resulting in energy, environmental, and cost benefits. Improved sensors will also enable better process stream characterization and control, and improve miner health and safety conditions.	The barriers to remote sensing include a lack of non-invasive technologies to quantify metal/mineral value in situ and to analyze special elements at ppm levels, a lack of navigation and guidance sensors for underground machines, and it does not work well underneath the forest canopy. The barriers to imaging include a lack of high-resolution imaging during drilling, real-time sensing for mineral content, and high-resolution, 3D tomography imaging between well bores. The barriers to health and safety include a lack of sensing devices for detection/measurement of gas, dust, noise, minerals positioning, and rocks.	Mineral content, ore grade, ore structure, ore continuity, gas concentration, noise level, dust	Sensors, imaging technologies, mineral deposit characterization, worker health and safety, remote sensing	High-resolution, real-time, remote sensing and imaging technologies
Nanotechnology	2003	Enhance discovery and marketability of nanotechnology applications following set standards and certification requirements.	Non-existent standards for nanomaterials	Safety, performance, physical properties, chemical properties	Nanotechnology, standards, properties, materials, nanomaterials	Standards development

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Nanotechnology	2003	The ability to safely make use of stored hydrogen can lead to its use as a source of clean energy.	Lack of verification of the technology's performance; safety concerns surrounding hydrogen storage	Physical properties, chemical properties, performance	Energy/petrochemicals, nanomaterials, properties	Metrology to support energy/petrochemicals; evaluation of carbon nanotubes for storing hydrogen
Nanotechnology	2003	Ultimately, the field offers a future of "electronics everywhere," with computing and processing power to be found in nanomaterials.	Silicon is near the end of possible improvements, and nanotechnology offers the way forward from silicon. However, molecular approaches are very different from silicon, in terms of band structure, of size (a million times smaller), of connectivity issues, and especially of fabrication approaches.	Quality, reducibility, scalablity, architecture	Molecular electronics, nanomaterials	Metrology to support molecular electronics: quality, reducibility, and scalability of devices and materials; novel architectures for computing and other devices
Nanotechnology	2003	Obtain ability to perform unintrusive detection-to-treatment in one visit.	Safety considerations for advancement over conventional therapies	Characterization, physical properties, chemical properties, performance	Nanomaterials, sensors, medicine/life sciences, healthcare	Metrology to support medicine/life sciences: mechanical and biological sensors, diagnostics including molecular aspects and contrast enhancement, and integrated operations
Nanotechnology	2003	Offer options for remote and less invasive functions: efficiency improvements in explosive and propellant materials through nanomaterials technology with factors of ten improvement due to higher surface areas for oxidation; improved efficiency for detection of hazardous materials; improved reliability of communications; surface modifications can address issues of dispersability and multifunctionality, enabling their use in biological systems or in aerospace composites	Appropriate and safe usage of materials for advancement over a variety of current technologies	Electrical and thermal conductivity, strength, physical properties, chemical properties, performance	Characterization, nanomaterials, aerospace, materials science	Metrology to support aerospace/materials science: material characterization (i.e., single-wall nanotubes)
Roadmap - Wisconsin Pulp and Paper Industry	2001	Standardized benchmark database to review energy efficiency and environmental impacts of pulp and paper processing could help manufacturers streamline pulp and paper production processes to improve yield and quality while reducing energy use and waste production.	N/A	Mass balance, waste composition, energy use, process variables	Pulp and paper, forest products, energy efficiency, waste minimization, Wisconsin	New methods to gather, analyze, and present environmental and energy efficiency data

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Mapping the Future in Science-Intensive Industries: Lessons From the Pharmaceutical Industry	2005					
The Food and Drug Administration's Strategic Action Plan Protecting and Advancing America's Health: Responding to New Challenges and Opportunities	2003	The pharmaceutical industry has historically paid less attention to continuous quality improvement in manufacturing processes than other high technology industries. New CGMP and quality inspection and compliance standards would reduce risk of poor quality products, allow utilization of new resources, and increase availability of safe FDA-regulated drug imports.	Increasingly complex and changing production processes for medicines and foods; CGMP regulations for drugs have not been updated for 25 years; pharmaceuticals manufacturers have not focused on quality improvements in manufacturing; inability to reliably ascertain the quality of imported drugs	Chemical composition, functionality, contaminants, mass, volume	Pharmaceuticals, drugs, CGMP, drug imports	Updated standards and practices for high-quality, cost-effective oversight of industry manufacturing, processing and distribution of drugs: updated Current Good Manufacturing Practices (CGMPs)
The Food and Drug Administration's Strategic Action Plan Protecting and Advancing America's Health: Responding to New Challenges and Opportunities	2003	Managing the safety of the food supply is of major concern to the FDA. New measurement and monitoring technologies would allow public health systems to quickly and accurately identify food safety hazards and manage disease risks. It would also help to ensure the security of the food supply against terrorist attacks.	Increasingly complex and changing production processes for medicines and foods; increase in emerging viruses and infections due to global trade and travel; broader food choices and imports create new kinds of vulnerabilities and risks	Pathogens, chemical composition, bacterial and microbial composition, elemental contaminants, mass, volume	Food, food processing, food safety, food-borne pathogens, food spoilage, food supply, food security	Measurement and detection systems to ensure the protection and safety of the food supply: intervention technologies used in Hazard Analysis and Critical Control Point (HACCP) systems; data and analytical methods for inspection and other compliance/enforcement activities; prevention standards and inspection and monitoring systems to assure food safety; expand capacity to test for agents that may be deliberately used to contaminate FDA-regulated products; research to develop rapid, confirmatory laboratory methods to analyze suspect foods
5th Annual CHP Roadmap Workshop	2004	Standard calculations are needed for comparison between various combined heat and power systems. Efficiency is a major milestone, and consistent calculation methodology is needed.	N/A	Efficiency	Combined heat and power, CHP, cogeneration, efficiency, standards	Develop efficiency calculation standards for combined heat and power systems.
A Climate Contingency Roadmap for the U.S. Electricity Sector: Phase II	2003					
A National Vision of America's Transition to a Hydrogen Economy	2002					
A Technology Roadmap for the Generation IV Nuclear Energy Systems	2002	Develop the property measurements and standards for advanced materials for nuclear power reactors.	Materials need to operate in a radiation environment and testing needs to reveal the materials degradation with neutron flux and dose. Public acceptance is based on rigorous material testing and traceable standards.	Physical, neutronic, thermal, and tensile properties, and their degradation under low to moderate neutron flux and dose	Reactor, nuclear, fuel, ceramics, radiation dose, reactor materials	Measurement and standards for physical, neutronic, thermal, and tensile properties, and their degradation under low to moderate neutron flux and dose
American Association of Petroleum Geologists (AAPG) Strategic Plan	2004					
An Integrated Roadmap for the Programmatic Resolution of Gas Generation Issues in Packages Containing Radioactive Waste/Materials	2001	Detectors/sensors and statistical models need to be developed that can work in the radioactive and hazardous environment in the presence of other gases. Assure that the measurements in the field are traceable to NIST standards.	The method of gas (hydrogen and oxygen) generation varies greatly depending upon the materials present. The measurements need to be made in sealed containers in the presence of radioactive and hazards materials and models developed to predict the levels of gas present in the containers.	Hydrogen and oxygen gas concentration levels	Radioactive materials, hydrogen, oxygen, hazardous materials, shipping and storage, explosive gas mixtures	Measurement of hydrogen and oxygen concentrations in nuclear shipping containers and storage facilities

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BESAC Subcommittee Workshop Report on 20-Year Basic Energy Sciences Facilities Roadmap	2003					
Biobased Products and Bioenergy Roadmap: Framework for a Vital New U.S. Industry	2001	Help support the development of economically viable separation and conversion processes for commercial use of a range of biobased feedstocks. Aid the development of a range of commercial set of front-end feed preparation systems that can handle a range of biobased inputs in an effective, preprocessing manner. Contribute to standards and benchmarks development for testing and validating new bioproducts and refining/processing techniques.	Limited ability to identify and solve major front-end limitations to biobased feedstock handling and preparation for processing	Size reduction, drying, solids feeding to pressurized vessels	Biomass, sensors, process control, feedstock handling, feedstock processing, feedstock preparation, analytical tool, quantification, bioenergy, bioproducts, biofuels	Low-cost, analytical bioproduct tools and cost/benefit evaluation models: a suite of analytical tools for characterization and quantification of bioproducts and bioenergy; improved, low-cost biomass analytical characterization methods with advanced sensors and fully integrative controls; develop and monetize full life-cycle development models for comparative real cost to market
Carbon Sequestration Technology Roadmap and Program Plan - 2004	2004	Wide scale use of carbon sequestration requires an accurate accounting of storage capacity and leakage. Need to develop instrumentation and protocols for tracking carbon uptake and storage in the first several feet of topsoil. The goal is a measurement protocol that enables 95% of stored carbon dioxide to be credited as net emissions reduction.	Difficulty in detecting small changes in concentration above the background emissions that already exist in the atmosphere, current on-the-ground measurements are accurate within 5-30%	Carbon dioxide concentration, biologic carbon storage	Carbon sequestration, greenhouse gas emissions, climate change mitigation	Capability to measure the amount of carbon dioxide stored at a specific soils sequestration site
Carbon Sequestration Technology Roadmap and Program Plan - 2004	2004	Wide scale use of carbon sequestration requires an accurate accounting of storage capacity and leakage. Need to develop instrumentation and protocols for tracking carbon storage in geologic formations. The goal is a measurement protocol that enables 95% of stored carbon dioxide to be credited as net emissions reduction.	Difficulty in detecting small changes in concentration above the background emissions that already exist in the atmosphere, 3D seismic can currently detect carbon dioxide with a resolution of 4 meters thickness	Carbon dioxide concentration, material permeability, geologic storage	Carbon sequestration, greenhouse gas emissions, climate change mitigation	Capability to measure the amount of carbon dioxide stored at a specific subsurface sequestration site
Carbon Sequestration Technology Roadmap and Program Plan - 2004	2004	Wide scale use of carbon sequestration requires an accurate accounting of storage capacity and leakage. Need to develop measurement tools to evaluate terrestrial carbon storage on a regional scale. The goal is a measurement protocol that enables 95% of stored carbon dioxide to be credited as net emissions reduction.	Difficulty in detecting small changes in concentration above the background emissions that already exist in the atmosphere, current practices provide fairly accurate measurements but are time and labor intensive	Carbon dioxide concentration, regional carbon storage	Carbon sequestration, greenhouse gas emissions, climate change mitigation	Capability to measure the amount of carbon dioxide stored at a specific above-ground sequestration site
Clean Cities Roadmap	2004	Predicting optimal fuel type for specific application, labeling and rating activities for vehicles relative to fuel economy	Lack of data consistency and varied assessment methods for comparing fuel price, incremental vehicle costs (which vary by fuel type), vehicle and fuel availability, and fuel properties	Fuel combustion	Alternative fuels, emissions, vehicle efficiency	Measurement technology to optimize fuel type for specific uses and activities
Clean Coal Technology Roadmap	2004	Geologic, ocean, soil ecosystem effects, and modeling capability	N/A	Carbon dioxide concentration, chemical	Carbon sequestration, greenhouse gas emissions, clean coal	Measure and verify carbon dioxide sequestration
Clean Coal Technology Roadmap	2004	N/A	Materials to use as sensors and controls of supercritical and ultra supercritical steam	Oxygen combustion	Clean coal, advanced combustion, sensors, controls	Sensors and controls for emissions, advanced combustion
Electric Cooperative Technology Solutions	2002					

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Fostering the Bioeconomic Revolution in Biobased Products and Bioenergy	2001					
Fuel Cell Report to Congress (ESECS-1973)	2003	Improve system integration and operation of fuel processors, cell stacks, and plant components. Foster mass market acceptance of fuel cell technologies.	Lack of guidance in R&D programs for advance technology compliance	Hydrogen storage capacity, efficiency, system architecture/infrastructure	Codes, standards, infrastructure, architecture, fuel cell hydrogen	Development of codes and standards: safety and liability aspects of fuel cell applications, system architectures, technology options, and infrastructure
Fuel Cell Report to Congress (ESECS-1973)	2003	Suitable measurement capability can lead to successful development of low cost, high performance components. High performance is required to improve power plant packaging for a given power output. Sensors are necessary for detecting hydrogen leaks and other safety related requirements.	Lack of satisfactory verification of fuel cell life/reliability characteristics.	Fuel cell performance/efficiency, reactivity, system safety	Sensors, safety, performance, reactivity, fuel cell, hydrogen	Measurement systems and control tools: sensors with proper ranges and selectivities for integrated fuel cell system application, characterization of fuel cell reliability
Fuel Cell Vehicles	2003	Improve system integration and operation of fuel processors, cell stacks, and plant components. Establish infrastructure, commercial viability, and market acceptance of fuel cell-powered vehicles.	Lack of guidance in R&D programs for advance technology compliance	Hydrogen storage and distribution, performance, infrastructure	Codes, standards, hydrogen, fuel cell, infrastructure, vehicle	Development of codes and standards: hydrogen storage and distribution, fuel cell vehicles, infrastructure
Fuel Cells for Buildings and Stationary Applications Roadmap Workshop	2002					
Grid 2030 - A National Vision For Electricity's Second 100 Years	2003	Develop improvements to the existing electric system and possibly advanced technologies that could revolutionize the electric grid.	Increased use of information technologies, computers, and consumer electronics has created lowered tolerances for outages, fluctuations in voltages and frequency levels, and other power quality disturbances. In addition, rising interest in distributed generation and electric storage devices is adding new requirements for interconnection and safe operation of electric distribution systems.	Transmission capacity, grid control, stability, quality, reliability, security	Electricity, electric grid, power distribution	Accelerate the "technical readiness" of critical electric systems, particularly for high-temperature superconducting cables and transformers, lower-cost electricity storage devices, standardized architectures and techniques for distributed intelligence and "smart power" systems, and cleaner power generation systems, including nuclear, clean coal, renewable, and distributed energy devices such as combined heat and power.
Hydrogen Posture Plan	2004	Publish codes and standards models by 2005. Technical codes and standards need to be in place to support regulatory standards by 2010. Commercialization of hydrogen technologies cannot proceed unless effective domestic and international (interoperable) codes and standards are in place.	Entirely new standards are needed, and will require time and resources to develop supporting data.	Chemical, physical, electrical, thermal, materials	Hydrogen, fuel cell, distributed energy, codes and standards, utility interconnection, interoperability	Hydrogen codes and equipment standards: development and dissemination of model building, fire, and safety codes; codes and standards for the hydrogen delivery infrastructure; utility interconnection and safety standards for hydrogen-fueled distributed energy devices; product safety and performance standards and design requirements for vehicles, fuel cells, storage tanks, and other products and equipment that use hydrogen; training and certification program for code and building officials; insurance rating of hydrogen energy systems; building codes that reference comprehensive equipment standards for hydrogen and fuel cell technologies for commercial and residential applications

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Hydrogen Posture Plan	2004	Publish safety standard for certification of a fuel cell vehicle.	Entirely new standards will be needed.	Fuel cell architecture	Fuel cell, hydrogen, safety standard	Safety testing and evaluation program for hydrogen fuel cell vehicles
Industrial Combustion Technology Roadmap	2002	Develop rugged sensor technologies that can exist in harsh environments.	Lack of measuring or sensing equipment that can take measurements of fuel ratio and temperature in the flame of the burner without intruding the combustion process; highly sensitive equipment for oxygen levels; measuring techniques for heat flux and profile	Thermal, chemical, fuel characteristics, combustion parameters	Combustion, temperature, sensors, real-time, heat, flux, burner, in-situ, NDE	Sensors for burners: low-cost, robust, non-intrusive device for in-flame measurement of temperature and fuel-air ratio; equipment sensitive enough to measure emissions and oxygen levels accurately; measurement techniques for measuring heat flux and profile
Industrial Combustion Technology Roadmap	2002	Develop rugged sensor technologies that can exist in harsh environments.	Sensors sensitive to low NOx emission levels; lack of sensors that can provide boiler data in real time, and at high temperature.	Thermal, highly sensitive NOx measurement, chemical, fuel characteristics, combustion parameters	Combustion, temperature, sensors, real-time, NOx, emissions, boiler, in-situ, NDE, real time	Sensors for Boilers: improved low-NOx measurement devices; durable sensors that can provide real-time measurements of combustion products; sensors that can provide high temperature measurements; improved measurement of steam use and temperature
Industrial Combustion Technology Roadmap	2002	Develop standard efficiency measure for furnaces. Develop rugged sensor technologies that can exist in harsh environments.	Lack of a standard measure of furnace efficiency; today's sensors are not 100 percent accurate for furnace temperatures and pressures; need sensors that can accurately measure fuel compositions in the furnace	Thermal, process variables, fuel characteristics	Combustion, temperature, sensors, real-time, NOx, emissions, furnace, fuel, in situ	Sensors for furnaces: common methods to measure furnace efficiency; non-traditional sensors for more accurate measurement of temperatures and physical properties; in situ real-time temperature sensing; robust sensors to measure critical parameters in harsh combustion environments; improved pressure measuring system and control device; sensors that can accurately measure fuel and oxidant compositional characteristics; real-time measurement of material failure
Micro-CHP Technologies Roadmap	2003	A set of metrics and benchmarks will ensure fair assessments and credibility in the field of heating and cooling, provide better characterization of unit performance, and establish standards for infrastructure.	Lack of baseline technical performance specifications for unit comparison and safety consideration	Efficiency, performance specifications, interconnectivity	Micro-combined heat and power, efficiency, performance, interconnectivity, standards, benchmarks	Development of standards and benchmarks: set of metrics for the micro cooling, heating, and power system; standardized interconnection rules; measurable benchmarks for efficiency, emissions, and reliability
Micro-CHP Technologies Roadmap	2003	Integrating controls and sensors will optimize the system's performance. The house would be able to communicate with the appliance to produce the optimal combination of heat and power, essentially making the mCHP the heart of a "smart" household and the controls the brain.	Current inability to prioritize loads, defer discretionary loads, and communicate with the electric grid; lack of relay protection for easy grid interconnection	Interoperability, performance	Micro-combined heat and power, controls, sensors, interoperability, performance, electric grid	Development of controls and sensors to define system architecture and interoperability
National Combined Heat and Power Roadmap	2001					
National Hydrogen Energy Roadmap	2002	Develop measurable cost-benefit analysis for electrolysis.	A better understanding of high temperature and high-pressure electrolysis is needed and could decrease costs.	Process variables, physical, chemical, cost	Electrolysis, hydrogen, energy	Develop measurable goals for electrolysis in terms of production efficiency, capital cost, and price
Roadmap for Biomass Technologies in the United States	2002	These systems should monitor and maintain feedstock quality through the collection, storage, and transportation phases of the product life cycle. They should provide producers with a better understanding of the quality of the feedstock. Additionally, systems should be developed to monitor growth so that harvesting can occur at the optimum time for processing and conversion.	Need for low-cost biomass sensors that enable real-time analysis of feedstock characteristics	Chemical, physical, functional	Energy, biomass, feedstocks, sensors	Sensors: quick, cost-effective systems for online real-time analysis and maintenance of plant and animal residue-based feedstocks

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Solar Electric Power: The U.S. Photovoltaic Industry Roadmap	2003	Technological innovations in process controls for PV systems will lead to technological innovations in PV manufacturing processes and enable more widespread use of lower-cost systems. The industry is seeking a 40-fold reduction in manufacturing costs by 2020.	Process controls for manufacturing PV components is inadequate, and automation is still insufficient to improve the cost efficiency of production.	Optical, photovoltaic properties, composition, light	Solar energy, solar power, photovoltaics, PV, renewables, controls, sensors, automation	Advance process controls and automation to improve the speed of manufacturing of photovoltaic (PV) components and reduce costs. Develop in-line diagnostic tools and systems to enhance process control and development. Develop high-volume, high-throughput, high-efficiency cell processes.
Solar Electric Power: The U.S. Photovoltaic Industry Roadmap	2003	Standardization will enable the development of technologically innovative "plug and play" PV systems that use standardized components, are preengineered and prepackaged, easy to maintain, and can be sold as a complete service solution to a much wider customer base.	Lack of standard module electrical/mechanical interfaces; lack of standard products, packages, and service offerings.	Electrical/mechanical interfaces	Solar energy, solar power, photovoltaics, PV, renewables, standards	Standards for common equipment used in PV systems: develop standard module electrical and mechanical interfaces, and standards for PV system components
Solid State Energy Conversion Alliance (SECA) Workshop : 2001 conference proceedings	2001	Improving the operation and lifetime while reducing the cost/watt of delivered power requires an understanding of the fundamental physical and chemistry process that govern the operation. This requires that detailed experimental measurement be compared with theory to evaluate different materials used in the fuel cells and to predict and evaluate future material performance.	The increased use of SOFCs depends upon the ability of the industry to improve SOFC operation, lifetime and reduce the cost/watt.	Bulk and surface material properties such as charge transfer, oxidation, transport, effects of sulfur in fuels	SOFC, anode, cathode, electrolyte, solid oxide fuel cell	Fundamental measurement systems for SOFC research: develop standard fundamental measurement systems to aid in the understanding of the physics and chemistry processes within the anode, cathode and electrolyte, and their interfaces
Status and Plans: The Fusion Simulation Project	2004	Achieve large code development and improved plasma diagnostics.	Development of large scale computer codes to model the complex behavior of fusion plasmas while coupling vastly different time and distance scale lengths; need to improve the accuracy of the plasma parameters to compare with the computer simulation	MHD stability of plasma, plasma profiles with radius, particle temperatures, plasma edge structure, fine scale turbulence parameters	MHD, computer simulation, SCIDAC, plasma physics, turbulence, electron and ion temperature, fusion	Computer modeling of fusion plasmas and improved diagnostics of plasma parameters
Technology Roadmap for the Petroleum Industry	2000	Online, real-time, accurate, non-intrusive, remote sensors and controls for measuring/monitoring stream compositions and properties and equipment condition assessment could be used to develop online intelligent processing systems, enabling maximum yields and more energy efficient processes while reducing maintenance and equipment costs. Improved particulate measurement techniques will facilitate PM 2.5 data collection and interpretation, thereby leading to methods to control particulates.	Inability to rapidly, precisely, and accurately obtain the composition of feeds and products as well as perform condition assessment of equipment; current composition sensors and analyzers are inadequate for non-intrusive, real-time applications; cost-effective, reliable sensors for leak detection are currently not available	Chemical composition, temperature, pressure, PM 2.5 emissions, hydrocarbon leaks/emissions, extent of fouling (heat transfer resistance), corrosion, structural integrity, thermal stability, solubility	Sensors, process control, chemical composition, intelligent processing systems, process automation, emission control, leak detection, condition assessment, fouling, corrosion, nondestructive evaluation, NDE	Improved sensors, controls, and measurement techniques: rapid, precise, accurate, non-intrusive, remote sensing and measurement devices for processes; develop new analytical and sampling techniques for measuring PM 2.5; improve remote sensors for fugitive emissions (leak detection) and site contamination/remediation; develop measurement techniques to detect the onset of fouling in heat exchangers, including the thermal stability and solubility characteristics of asphaltenes with/without fouling precursors such as iron or sulfur compounds; develop global, online, noninvasive, nondestructive inspection techniques to detect loss of containment, corrosion, flaws in material structural integrity (note that global implies the inspection occurs at locations remote from the probes)
Technology Roadmap for the Petroleum Industry	2000	An agreed-upon method for risk assessment will help ensure that environmental regulations are based on up-to-date, verifiable, quantified risks.	Lack of toxicology database to support risk assessment, and quick, inexpensive methods for evaluating toxicity	Toxicity	Risk assessment, toxicity, health and environmental safety, database	Measurements to support improved environmental performance of petroleum refineries: develop an agreed-upon method for risk assessment, emphasizing toxicity and exposure to humans, uncertainties in extrapolation of data from animals to humans, and new approaches for current assessment tools with conservative assumptions; develop inexpensive, quick methods for evaluating toxicity

APPENDIX B: DETAILED ROADMAP MEASUREMENT NEEDS

Title	Report Year	Technology Innovation	Technical Barriers	Properties Of Interest	Keywords	Measurement Need
The Electricity Technology Roadmap Initiative	2003	The increased use of digital technologies requiring high quality electricity is increasing strain on today's power transmission grid. The grid does not have the capability, control or stability needed to meet 21st century needs for power availability, reliability, quality and security. Dramatic technological changes are proposed, including a self-healing grid, power electronics-based integrated network control (using post-silicon power electronics), embedded fiber optics, and other innovations. A wide-area measurement system that supports advanced grid monitoring is key to the radical innovation of the existing grid, and will provide critical data for both self-healing systems and new infrastructure security systems.	Today's power system is aging and significant upgrades and investment will be needed to incorporate advanced technologies. WAMS are currently being developed, but still require advanced sensors and communication interfaces with phasor measurement units, GPS satellite systems, and the power network. Implementation is being hampered by cost and availability of standard solutions with real-time capability, which is critical to the concept.	Power, voltage, current waveforms, phasor magnitudes and angles, temperature	Grid, transmission grid, power, electricity, wide area measurement systems, WAMS, sensors, self-healing	Wide area measurement systems (WAMS) technology for "smart" power delivery: develop advanced sensors and measurement technology to support wide-area system monitoring and control and enable faster-than-real-time data processing for control of self-healing power grids
The Electricity Technology Roadmap Initiative	2003	Enabling developments in sensors and measurement technology are critical to the evolution of a technologically advanced transmission grid capable of global electrification. Innovative technology approaches include acoustic wave sensors, electrochemical microsensors; increased temperature resistance of optical fibers, sensor housings, claddings and adhesives; low-cost versatile fiber Bragg gratings; and microminiaturization of sensor components.	Crosscutting multi-disciplinary R&D will be needed to develop enabling sensors and measurement technologies for advanced power systems. R&D is long-term and costly as well as technically risky.	Power, voltage, current waveforms, phasor magnitudes and angles, temperature, chemical composition, criteria air pollutants	Grid, transmission grid, power, electricity, sensors, electrification, enabling technology	Enabling measurement technologies for advanced power systems: real-time condition assessment of critical components to support smart materials development; real-time measurements of emissions and waste streams; microsensors for voltage and current; distributed temperature measurement in transformer windings; specialized sensors for chemical species and high temperature environments
The Technology Roadmap: Energy Loss Reduction and Recovery in Industrial Energy Systems	2004	Significant amounts of energy are wasted annually in the form of waste heat and byproducts from industrial processes. New energy recovery technologies are needed to capture waste energy resources as well as store and transport waste energy.	Entirely new standards will be needed.	Thermal, physical, chemical	Heat recovery, waste heat, industrial processes, standards	Standards for heat recovery equipment designs to establish commonality and reduce costs
The Technology Roadmap: Energy Loss Reduction and Recovery in Industrial Energy Systems	2004	Product specification can be met while minimizing energy use and cost, and ultimately achieve reductions in heat requirements. Technology includes those with effective optimization of process heater operations and innovations that enable automation of process heaters, including those that better control or reduce environmental emissions such as Nox	Severe operating environments (temperature, pressure); corrosive environments	physical, proces variables, product quality	Sensor systems, industrial processes, heat reduction, energy use, Nox	There is a need for sensor systems to facilitate energy source flexibility and heat reduction process optimization. These may include remote measurement of temperature and pressure, direct measurement of product parameters, predictive models, automated process heaters, controls, and other technology to optimize heat reduction and energy use.
The Technology Roadmap: Energy Loss Reduction and Recovery in Industrial Energy Systems	2004	Can lead to improvements such as: better heat transfer mechanisms; innovative equipment and working fluids; economic recovery of waste heat from exit gases (including those with containing corrosives or contaminants).	Inadequate materials (e.g., corrosion resistant); Insufficient understanding of industry needs; Lack of knowledge about which technologies are the best fit for various applications	heat recovery and transfer benchmarks, performance	heat recovery, heat transfer, benchmarks industrial processes	Benchmarking and comparison of various technologies to determine best use of recovered heat and different heat transfer methods
U.S. Photovoltaics Industry Roadmap	2004	N/A	N/A	Electric power, standards, electrical	Electric metering, solar power	Establish uniform net metering and interconnection standards to give solar power owners the right to simple, equitable access to the grid and fair compensation for the value of the solar power they supply.

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U.S. Small Wind Turbine Industry Roadmap	2002	Accelerate the use of wind turbines through better characterization of ecological and societal impacts.	Presently, there are no noise measurement standards for wind turbines, as this is still a technology at the initial steps of its market penetration.	Wind currents, noise	Wind, standards, noise levels	Develop noise measurement standards for wind turbines.
Vision for Bioenergy & Biobased Products in the United States	2002					
Nanoscience Research for Energy Needs	2004	Obtain the ability to make uniform catalysts that can be understood fundamentally, without the complications of non-uniform materials that have a range of catalytic properties. Utilize catalysts with performance characteristics rivaling those of enzymes. Ultimately, these research efforts can be applied to create new catalysts that will allow economical, one-step conversion of methane into methanol or other liquid fuels; cellulosic raw materials or CO2 into liquid fuels; H2, methanol, or gasoline conversion; or potential onboard conversion of liquid fuels into H2 for fuel cells, eliminating hydrogen storage.	There is a current inability to predict performance and structure/compositions of catalytic nanomaterials in reactive environments. The necessity to acquire a fundamental understanding of nanomaterials in reactive material will require improved and novel methods, instruments, and facilities.	Compositions, structures, sizes, morphologies, degree of uniformity of nanoparticles, nanoporous materials, and their combinations and interfaces	Catalysis, catalysts, energy, nanostructures, nanomaterials, nanoscale, nanoparticles, nanoporous, performance, characterization, infrastructure	Metrology/infrastructure to support catalysis by nanoscale materials: performance assessments, advanced computation, novel imaging techniques, spectroscopic characterization methods
Nanoscience Research for Energy Needs	2004	Obtain the ability to control energy transport across nanoscale interfaces for advances in energy use and energy harvesting, such as efficient power handling; low-power electronics; thermoelectric energy conversion; nanostructured photovoltaics; and efficient energy use in lighting (solid-state lighting, organic light-emitting diodes).	The need to create interfaces tailored at the nanoscale to optimize energy transport in many forms (electrons, phonons, photons, excitons) requires assessing material performance at the nanoscale interfaces.	Material properties, chemical properties, electrical properties, optical properties, conductivity, efficiency, performance	Nanostructures, nanomaterials, nanoscale, nanoparticles, energy transport, interfaces, performance, characterization, efficiency	Metrology/infrastructure to support the use of engineered nanostructures at interfaces to manipulate energy carriers: intelligent design of experiments based on theory and modeling; optimizing materials and chemistry choices; in situ characterization to directly establish structure/property relationships
Nanoscience Research for Energy Needs	2004	A more complete picture of the molecular structure and evolution of nanoscale materials to permit the prediction, design, and assembly of functional nanostructures would enable the rational architectural design of new materials for a wide range of important energy applications (mass and energy transport, energy storage, energy conversion, energy production).	The overarching difficulty in designing novel nanomaterials is establishing the physical and chemical principles that relate the changes in molecular structure to the functionality that emerges at nanometer length-scales.	Physical properties, chemical properties, optical properties, geometries, structural/functional relationship	Nanostructures, nanomaterials, nanoscale, nanoparticles, characterization tools, modeling, functionality, assembly, architecture, energy applications	Metrology to link nanoscale structure and function for nanomaterial assembly and architecture: characterization tools, theory, and modeling/imaging/computational simulations; temporal and spatial scales

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Nanoscience Research for Energy Needs	2004	Develop nanomaterial systems that are able to deliver greatly enhanced properties at the macro scale: defect-free nanomaterials with sufficiently high purity; economical, large-scale production of high-quality nanomaterials; and expanded library of enhanced nanomaterial properties. Synthesis that involves carbon nanotube materials, nanocrystals, bio-nanomaterial hybrids, ternary and more complex nanomaterials, combinatorial techniques and highly parallel sorting, nanoscale materials for storing hydrogen, organic materials, optoelectronics, and functional bulk materials can all potentially have the highest impact on U.S. energy security.	Further research and understanding is necessary for the synthesis of practical nanomaterials leading to fabrication/processing and system design techniques that preserve unique nanoscale properties while coupling them to the macroscale.	Quality, quantity, variety, and scalability/design/assembly of nanomaterials and their properties/functionalities (nano-functionalities include conductivity, field emission, catalyst support, gas adsorption, etc.)	Nanostructures, nanomaterials, nanoscale, nanoparticles, characterization tools, modeling, functionality, assembly, architecture, scaleable synthesis, energy applications	Metrology/infrastructure to support scaleable synthesis: advanced characterization tools and modeling; network of laboratories and universities; neutron characterization facilities (time-resolved in situ neutron scattering studies for energy applications); high-brightness synchrotron sources; electron-based techniques
Exploring Our Future: Technical Communication in the Year 2013	2003					
The UK Publishing Industry: Becoming the Public Face of Knowledge Engineering	2002					
Radio Frequency Identification	2005	Technological challenges need to be addressed for electromagnetic interference, and operation with conductive material. Address and develop technical standards for frequency and power levels.	Development of a mature technology; agreement on standards for hardware/software and wireless spectrum operations; privacy and security concerns and total system cost reduction	Power level, frequency of operation, standards	RFID, tags readers, EPC, UPC, EZ Pass	Measure system parameters and develop international standards acceptable to the industry
Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2002 NAE Symposium on Frontiers of Engineering	2003	The development of nano structures for industrial appplications such as continued miniaturation of semiconductors and medical sensors will be limited by the ability to make them. The manufacturing is presently limited by the fundamental understanding of the properties of these structures and how they change with size.	Physical and chemical properties become dependent upon quantum-level electronic structure as the size diminishes to <100nm	Transition temperatures, diffusion coefficients, thermal and electrical properties, etc.	Nano structures, mechanical, electrical, thermal, magnetic, size/dimensions, temperatures, quantum	Measure nano-structures mechanical properties as a function of size/dimension, eg real-time deformations of nanostructures
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies greater than or equal to 45 nm.	Standards for process controllers and data management must be agreed upon. Convert massive quantities of raw data into information useful for enhancing the yield of semiconductor manufacturing process. Better sensors must be developed for trench etch end point, ion species/energy/dosage (current), and wafer temperature during rapid thermal anneal.	Physical	Semiconductors, sensors, process controllers, data conversion, data management	Factory level and company wide metrology integration for real-time in situ, integrated, and inline metrology tools; continued development of robust sensors and process controllers; data management that allows integration of add-on sensors
International Technology Roadmap for Semiconductors	2004	Critical dimension, film thickness and defect detection are impacted by thin silicon on insulator optical properties and charging by electron and ion beams. Improve capabilities and understanding for semiconductor technologies greater than or equal to 45 nm.	Existing capabilities do not meet specified needs. Very small particles must be detected and properly sized. Capability for silicon on insulator wafers needs enhancement. Challenges come from the extra optical reflection in silicon on insulator and the surface quality.	Physical	Semiconductors, particle detection, silicon on insulator, SOI	Impurity detection (especially particles) at the levels of interest for starting materials and reduced edge exclusion for metrology tools
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies greater than or equal to 45 nm.	Control of high-aspect ratio technologies such as damascene (process in which interconnect metal lines are delineated in dielectrics isolating them from each other not by means of lithography and etching, but by means of chemical-mechanical planarization) challenges all metrology methods.	Physical and electrical	Semiconductors, void detection, damascene, pore detection	Improved metrology with high-aspect ratio technologies: key requirements are dimensional control, void detection in copper lines, and pore size distribution and detection of killer pores in patterned low-kappa dielectrics

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International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies greater than or equal to 45 nm.	Reference materials and standard measurement methodology is needed for new, high-kappa gate and capacitor dielectrics with engineered thin films and interface layers, as well as interconnect barrier and low-kappa dielectric layers, and other process needs. Optical measurement of gate and capacitor dielectric averages over too large an area and needs to characterize interfacial layers. Carrier mobility characterization will be needed for stacks with strained silicon and silicon on insulator substrates. The same is true for measurement of barrier layers.	Physical and electrical	Semiconductors, material stacks, interfacial properties, silicon on insulator, SOI	Measurement of complex material stacks and interfacial properties including physical and electrical properties
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies greater than or equal to 45 nm.	The area available for test structures is being reduced especially in the scribe lines. There is a concern that measurements on test structures located in scribe lines do not correlate with in-die performance. Overlay and other test structures are sensitive to process variation, and test structure design must be improved to ensure correlation between measurements in the scribe line and on chip properties. Standards institutions need rapid access to state of the art development and manufacturing capability to fabricate relevant reference materials.	Standards	Semiconductors, test structures, reference materials	Measurement test structures and reference materials
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies less than 45 nm.	Surface charging and contamination interfere with electron beam imaging. Critical dimension measurements must account for sidewall shape. Critical dimension for damascene (process in which interconnect metal lines are delineated in dielectrics isolating them from each other not by means of lithography and etching, but by means of chemical-mechanical planarization) process may require measurement of trench structures. Process control such as focus exposure and etch bias will require greater precision and 3D capability.	Physical	Semiconductors, damascene, microscopy	Nondestructive, production worthy wafer and mask level microscopy for critical dimension measurement for 3D structures, overlay, defect detection, and analysis
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies less than 45 nm.	Correlation of test structure variations with in-die properties is becoming more difficult as device shrinks.	Physical	Semiconductors, in-die metrology, test structure	New strategy for in-die metrology must reflect across chip and across wafer variation.
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies less than 45 nm.	Controlling processes where the natural stochastic variation limits metrology will be difficult. Examples are low-does implant, thin gate dielectrics, and edge roughness of very small structures.	Physical and electrical	Semiconductors, process control, gate dielectrics	Statistical limits of sub-45 nm process control
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies less than 45 nm.	Materials characterization and metrology methods are needed for control of interfacial layers, dopant positions, and atomic concentrations relative to device dimensions. One example is 3D dopant profiling.	Physical	Semiconductors, interfacial layers, 3D dopant profiling	Structural and elemental analysis at device dimensions
International Technology Roadmap for Semiconductors	2004	Improve capabilities and understanding for semiconductor technologies less than 45 nm.	The replacement devices for the transistor and structure and materials replacement for copper interconnect are being researched.	Physical	Semiconductors, manufacturing metrology, interconnect technology, copper interconnect	Determination of manufacturing metrology when device and interconnect technology remain undefined
International Technology Roadmap for Semiconductors	2004	Make a transition from a destructive physical inspection process to a primarily non-destructive diagnostic capability. Improve test, test equipment capabilities, and understanding for semiconductor technologies less than 45 nm.	Failure analysis methods for analog devices must be developed and automated.	Physical	Semiconductors, defect analysis, failure analysis, testing, automatic test equipment	Real-time analysis of defects in multi-layer metal processes; characterization capabilities must identify, locate, and distinguish individual defect types
International Technology Roadmap for Semiconductors	2004	Improve efficiency and reduce design complexities associated with test. Improve test and test equipment capabilities and understanding for semiconductor technologies less than 45 nm.	Fundamental research in existing and novel fault models to address emerging defects is required. Significant advances in electronic data automation tools for automatic test pattern generation capacity and performance for advanced fault models and design for testability insertion are also needed.	Physical	Semiconductors, defect analysis, testing, automatic test equipment	Improved defect analysis: defect types and behavior will continue to evolve with advances in fabrication process technology

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International Technology Roadmap for Semiconductors	2004	Enable pre-silicon test development and minimize costly post-silicon test content development/debugging on expensive automatic test equipment. Improve test and test equipment capabilities and understanding for semiconductor technologies greater than or equal to 45 nm.	High-performance digital and analog input/output and power requirements require significant improvements to test environment simulation capability to ensure signal accuracy and power quality at the die. Equipment suppliers must provide accurate simulation models for pin electronics, power supplies, and device interfaces to enable interface design.	Physical	Semiconductors, simulation, testing, automatic test equipment	Simulation of automatic test equipment, device interfaces and devices under test with highly accurate logic and timing is needed to enable pre-silicon test development and minimize costly post-silicon test content development/debugging on expensive automatic test equipment.
International Technology Roadmap for Semiconductors	2004	Improve emerging research device capabilities and understanding for semiconductor technologies less than 32 nm.	The primary tools to extract properties at the nanometer scale measure structural information, so critical material properties are not measured at these dimensions. It is difficult to characterize 2D/3D chemical, structural, electronic, and atomic bonding at the nanometer scale, and separation of bulk and interface properties becomes more difficult as the surface becomes a large part of the material.	Physical	Semiconductors, charge transport	The characterization of critical material properties at the nanometer scale for both charge transport and non-charge transport-based devices is very limited and may hinder the ability to improve materials properties.
International Technology Roadmap for Semiconductors	2004	Improve emerging research device capabilities and understanding for semiconductor technologies less than 32 nm.	Modeling tools are very inaccurate in predicting excited states, and these are critical in modeling transport through materials or across interfaces. Correlation effects become significant at small material size, but these are not currently modeled.	Physical	Semiconductors, physical models, nanometer materials	For modeling and simulation to predict the right trends of properties of nanometer sized materials, correct physical models must be developed.
International Technology Roadmap for Semiconductors	2004	Improve lithography capabilities and understanding for semiconductor technologies less than 45 nm.	N/A	Physical	Semiconductors, lithography, critical dimension, defects	Metrology and defect inspection: resolution and precision for critical dimension measurement down to 7 nm, including metrology for 2.2. nm 3 sigma line width roughness; metrology for overlay down to 7.2 nm; defect inspection for patterned wafers for defects less than 30 nm
International Technology Roadmap for Semiconductors	2004	Improve environment, safety and health risks related to semiconductor technologies greater than or equal to 50 nm.	Limited knowledge base on health and safety characteristics of chemicals, materials, and process byproducts in the manufacturing and maintenance processes. The potential for chemical exposures and the need for personal protective equipment currently exist.	Chemical and biological	Semiconductors, environment, safety, health, chemicals, ES&H	Need quality rapid assessment methodologies to ensure that new chemicals (or those carried over from previous technologies but that now face new restrictions) can be utilized in manufacturing, while protecting human health, safety, and the environment without delaying process implementation.
International Technology Roadmap for Semiconductors	2004	Improve yield enhancement for semiconductor technologies greater than or equal to 45 nm.	Develop understanding of systematic mechanism limited yield to achieve historic yield ramps in the future. Improve signal to noise ratio to delineate defect from process variation. In-line and end-of-line failure analysis tools and techniques are needed to enable localization of defects where no visual defect is detected.	Physical	Semiconductors, yield, models, defects	Develop parametric sensitive yield models including new materials and in consideration of the high complexity of integration; detection of ever shrinking yield critical defects
International Technology Roadmap for Semiconductors	2004	Improve yield enhancement for semiconductor technologies greater than or equal to 45 nm.	Poor transmission of energy into bottom of via and back out to detection system; large number of contacts and vias per wafer	Physical	Semiconductors, yield, defects	High-aspect-ratio inspection: high-speed, cost-effective tools are needed to rapidly detect defects at 1/2 X ground rule associated with high-aspect-ratio contact, via, and trenches, especially defects near or at the bottoms of these features
International Technology Roadmap for Semiconductors	2004	Improve yield enhancement for semiconductor technologies greater than or equal to 45 nm.	Development of automated, intelligent structures, analysis, and reduction algorithms that correlate facility, design, process, test, and work-in-process data	Physical	Semiconductors, yield, test structures, data management	Data management and test structures for rapid yield learning to enable the rapid root-cause analysis of yield-limiting conditions
International Technology Roadmap for Semiconductors	2004	Improve yield enhancement for semiconductor technologies less than 45 nm.	Need to understand relative importance of different contaminants to wafer yield, and need methodology for employment and correlation of fluid/gas types to yield of a standard test structure/product.	Standards, physical	Semiconductors, yield, contaminants, impurity, fluids, water	Define a standard test for yield/parametric effect to correlate impurity level to yield. Data, test structures, and methods are needed for correlating process fluid contamination types and levels to yield and to determine required control limits.

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International Technology Roadmap for Semiconductors	2004	Improve yield enhancement for semiconductor technologies less than 45 nm	Existing techniques exchange throughput for sensitivity, but at predicted defect levels, both throughput and sensitivity are necessary for statistical validity. The ability to detect particles at critical size may not exist.	Physical	Semiconductors, yield, defects	Detection and simultaneous differentiation of multiple killer defect types is necessary at high capture rates and throughput.
International Technology Roadmap for Semiconductors	2004	Develop novel nanostructure devices, and improve modeling and simulation capabilities for semiconductor technologies less than 45 nm.	N/A	Physical	Semiconductors, modeling, simulation, nanostructure devices	Nano-scale modeling: process modeling tools, device modeling tools for analysis of nanoscale device operation
International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies less than 45 nm.	Need computational materials science tools to describe materials properties, process options, and operating behavior for new materials applied in devices and interconnects, especially for the following: gate stacks; predictive modeling of dielectric constant; bulk polarization charge; surface states; thermomechanics (including stress effects on mobility); optical properties; reliability; breakdown; leakage currents including band structure; tunneling from process/materials; and structure conditions.	Chemical, electrical	Semiconductors, modeling, simulation, interconnects, materials	Modeling of chemical, thermomechanical, and electrical properties of new materials; models for air gap and novel integrations in 3D interconnects including data for ultrathin material properties
International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies greater than or equal to 45 nm.	Model thermal-mechanical, thermodynamic and electronic properties of low-kappa, high-kappa, and conductors, and the impact of processing on these properties especially for interfaces and films under 1 micron dimension. Model reliability of packages and interconnects (e.g., stress voiding, electromigration, piezoelectric effects, textures, fracture, adhesion). Also, develop models for electron transport in ultra fine patterned conductors.	Thermodynamics, electrical	Semiconductors, modeling, simulation, thermal-mechanical, thermodynamic, electrical, interconnections, packaging	Thermal-mechanical-electrical modeling for interconnections and packaging
International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies greater than or equal to 45 nm.	Fundamental physical data, reaction mechanisms, reduced models for complex chemistry; linked equipment/feature scale models; multi-generation equipment/wafer models; chemical mechanical planarization modeling; metal-organic chemical vapor deposition modeling; plasma-enhanced chemical vapor deposition modeling; atomic layer deposition modeling; electroplating and electroless deposition modeling	Physical	Semiconductors, modeling, simulation	Integrated modeling of equipment, materials, feature scale processes and influence on devices
International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies greater than or equal to 45 nm.	Diffusion/activation/damage models and parameters; characterization tools/methodologies for these ultra shallow geometries/junctions and low dopant levels; modeling hierarchy from atomistic to continuum for dopants and defects in bulk and at interfaces; front-end processing impact on reliability	Physical	Semiconductors, modeling, simulation, nanometer structures	Front-end process modeling for nanometer structures
International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies greater than or equal to 45 nm.	Efficient extraction and simulation of full-chip interconnect delay; accurate and yet efficient 3D interconnect models, especially for transmission lines and S-parameters; extension of physical device models; high-frequency circuit models including non-quasi-static, substrate noise, parasitic coupling; parameter extraction assisted by numerical electrical simulation instead of RF measurement; scalable active and passive component models for compact circuit simulation; co-design between interconnects and packaging	Physical	Semiconductors, modeling, simulation	High-frequency device and circuit modeling for 5-100 GHz applications

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International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies greater than or equal to 45 nm.	Optical simulation of resolution enhancement techniques including mask optimization; predictive resist models including line-edge roughness, etch resistance, adhesion, and mechanical stability; methods to easily calibrate resist model kinetic and transport parameters; models that bridge requirements of speed; experimental verification and simulation of ultra-high numerical aperture vector models, including polarization; models and experimental verification of non-optical immersion lithography effects; multi-generation lithography system models; simulation of defect influences/defect printing	Physical	Semiconductors, lithography, modeling, simulation	Lithography simulation including next generation lithography
International Technology Roadmap for Semiconductors	2004	Improve modeling and simulation capabilities for semiconductor technologies greater than or equal to 45 nm.	Methods and algorithms that contribute to prediction of CMOS limits; quantum based simulators; models and analysis to enable design and evaluation of devices and architectures beyond traditional planar CMOS; gate stack models for ultra-thin devices; models for device impact of statistical fluctuations in structures and dopant distributions; phenomenological material models for stress engineering	Physical	Semiconductors, CMOS, complementary metal oxide semiconductor, modeling, simulation	Ultimate nanoscale complementary metal oxide semiconductor (CMOS) simulation capability
The State-of-Art and Future Trends in Testing Embedded Memories	2004	The importance of developing new fault models increases with the new memory technologies. Shrinking technology will be a source of previously unknown defects/faults. The traditional tests are becoming insufficient and inadequate for high speed memories. Diagnosis techniques play a key role during the rapid development of semiconductor memories for catching design and/or manufacturing errors and failures, hence improving the yield.	The majority of tests currently used in the industry have been designed to target static faults and therefore may not detect/diagnose dynamic faults. Tests that incorporate the dynamic fault class are currently limited by a need to establish the complete fault space, the fault framework, validation based on defect injection and SPICE simulation, inductive fault analysis that determines the occurrence probabilities and the importance of each introduced fault model, and understanding of the underlying defects causing dynamic faults.	Fault modeling	Embedded memories, semiconductors, fault modeling, testing and diagnosis, circuit simulation, defects	Fault modeling that reflects the real defects of new memory technologies and tests to catch/locate defective cells are needed. Such tests need to consider the following: optimize for time complexity; regularity and symmetry so the self-test circuit can minimize the silicon area; high defect coverage and diagnosis capability; and appropriate stress combinations (voltage, temperature, timing, etc.) that facilitate the detection of marginal faults.
Nanoelectronics-Silicon and Beyond Workshop Report - Executive Summary	2003	Sustain the scaling of complimentary metal oxide semiconductor (CMOS) manufacturing technology to its ultimate limit. Provide alternative, scalable, and sustainable benign-high performance materials and manufacturing technologies for CMOS alternatives. Create options for integrating heterogeneous nanoengineered functional materials with CMOS technology, thereby enabling a commercialization path for nanotechnology innovations.	It is increasingly difficult for known bulk material systems and processes to address projected dimensional, performance, energy management, and manufacturing requirements in the next five to seven years. There is a lack of new materials that satisfy projected performance and insertion timing requirements, and a lack of robust and affordable nanoscale fabrication options.	Energy efficiency, scalability, sensitivity to parameter variations, room temperature operation, reliability, stability	Nanoelectronics, modeling, characterization, design, infrastructure, performance	Interdependent predictive modeling, design, characterization, and experimental materials assembly infrastructure
Nanoelectronics-Silicon and Beyond Workshop Report - Executive Summary	2003	Develop evolutionary material and process enhancements that enable affordable fabrication and extensibility of CMOS nanostructures. Achieve robust integration and directed self assembly of heterogeneous materials onto a silicon platform, as well as novel 3D nanomaterial systems with deterministic architectures.	Known characterization and metrology capabilities are approaching their limits, with no known solutions existing that address the real-time, non-destructive characterization and reliability requirements of deep nanoscale materials and nanostructures.	Composition, dimensionality, reliability, defectivity, and functionality at the nano, molecular, and atomic scales	Nanomaterials, characterization, metrology, tools, architecture, design, performance	Characterization and metrology of nanomaterials and graded composites; tools and methodologies for nanoelectronic design and architecture
2004 Telecommunications Industry Playbook	2004					

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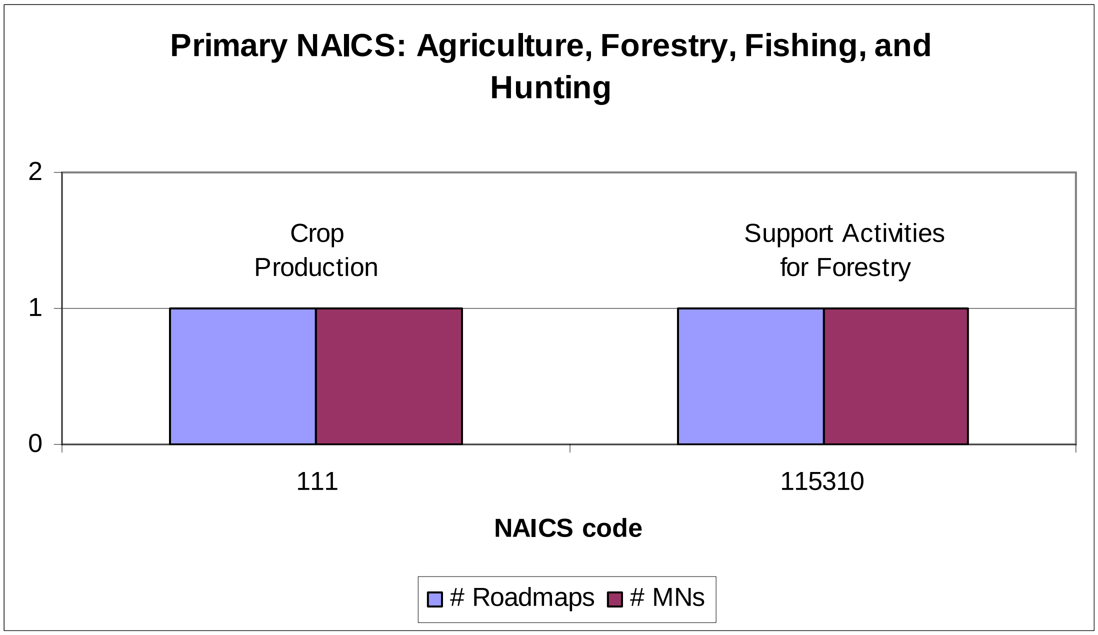
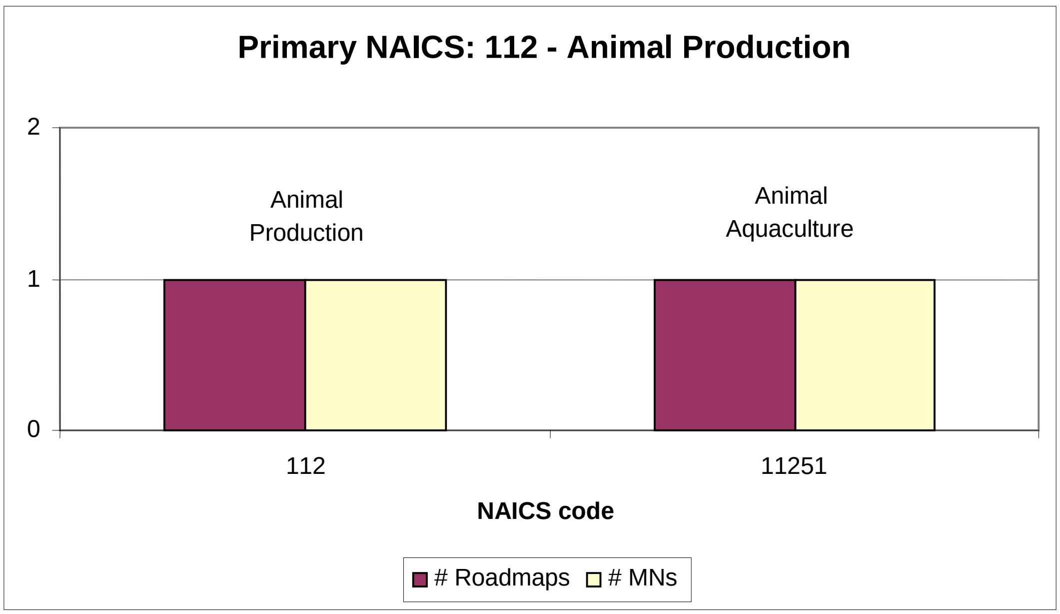
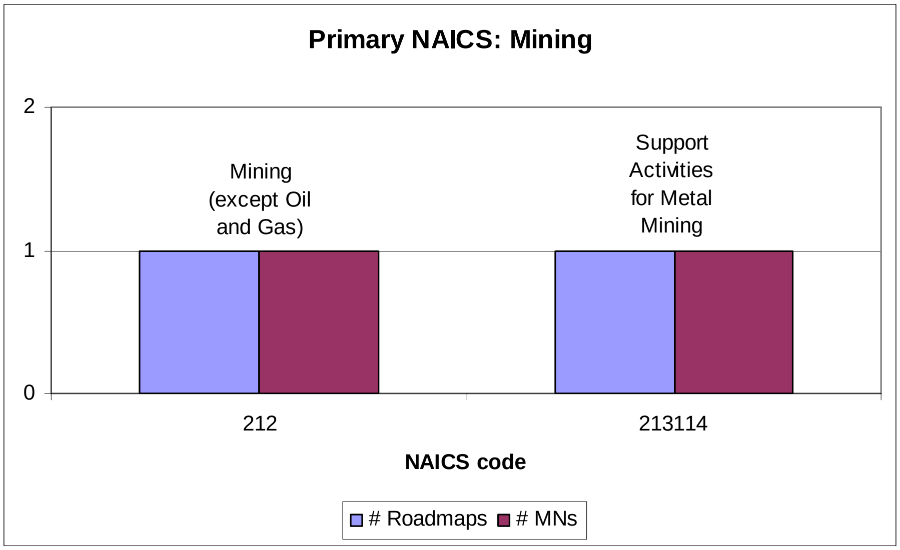
IST Roadmap for Optical Communications	2002	Develop standards that will allow cutting edge development while ensuring the technology will be compatible worldwide. Standards will be needed for optical transmission and security for the optical communications systems.	The rapid pace of alternate competing technologies will drive the need for world wide standards if the technology is to be successful.	Communications security standards, and standards for optical communications systems such as Optical Burst Switching (OBS) and Optical Packet Switching (OPS), software assurance	Receivers, transmitters, communications security standards, network, optoelectronic, digital, global	Continued development of measurements and standards for optical communications equipment and software including security standards
Technology Foresight: Industrial Wireless Technology for the 21st Century	2004	A flexible quality-of-service model would measure appropriateness of various wireless sensor networks in specific local settings.	N/A	Interference	Wireless network, wireless sensor, radio frequencies, interference	Ability to predict the quality of service that can be expected from a wireless sensor network, given local interference factors
The Science Ahead	2002	Develop secure high-speed communication networks for worldwide researchers.	The vast amounts of data generated by High Energy Physics Experiments and the need to share the data with researchers around the world in a secure manner	Network security, data rates	High energy physics, communications networks, particle acceleration	Continued development of ultra high-speed worldwide standard secure communications systems to allow the researchers to effective share the huge amounts of data generated in the next generation of experiments and theoretical calculations
NCSLI Strategic Roadmap for Metrology Education & Training	2005					
Department of Transportation Strategic Plan 2003-2008: Safer, Simpler, Smarter Transportation Solutions	2003	Enhance technology for the protection of the confidentiality, integrity, and availability of all Department of Transportation information technology assets.	Vulnerability to attack and other service disruptions, including those caused by natural disasters	Software vulnerabilities, software security, cyber security	Information technology, department of transportation, software security, software vulnerability, homeland security	Security protocols for information technology systems: identification, evaluation, and mitigation of vulnerabilities
Railroad and Locomotive Technology Roadmap	2002	Combine NOx and PM sensors together with closed-loop emission control systems.	The primary technical barrier is related to the durability that is required for the severe locomotive environment.	The ability to detect NOx and PM emissions will allow needed combustion (in-cylinder) and after treatment device control.	Rail transport, emissions, sensors	Emissions sensors for locomotives capable of measuring NOx and particulate matter levels
Riding on Light - Optical Technology for Transportation Challenges	2003	Increase sensitivity to unknown sources such as chemical, biological, radiological and explosives, while increasing reliability and ruggedness at reduced cost per measurement.	Improve sensitivity, miniaturation and ability to operate in harsh environments routinely encountered in the air, and on land and sea transportation.	Chemical, biological, radiological, nuclear and explosive	Spectroscopy, optics, photonics, hazard detection, sensors	Improved chemical, biological, radiological, nuclear and explosive measurements and sensors

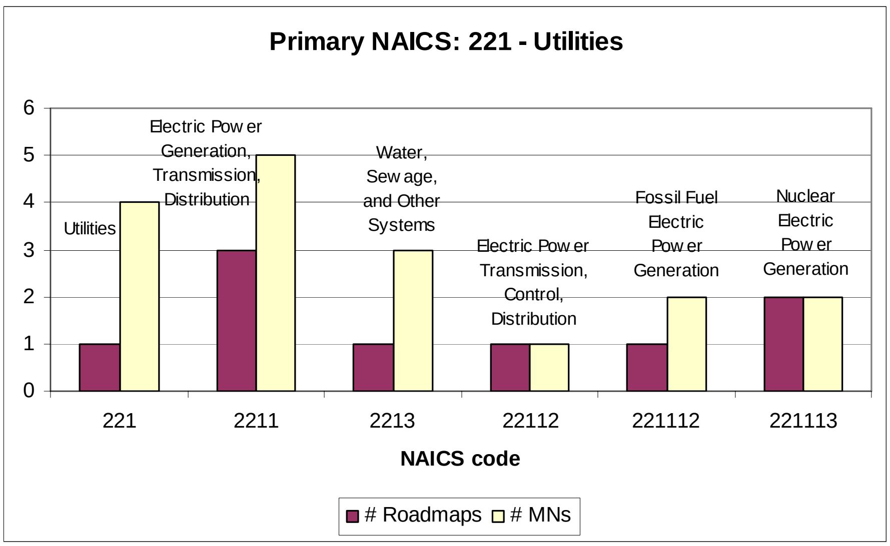
APPENDIX C: NAICS MAPPING RESULTS

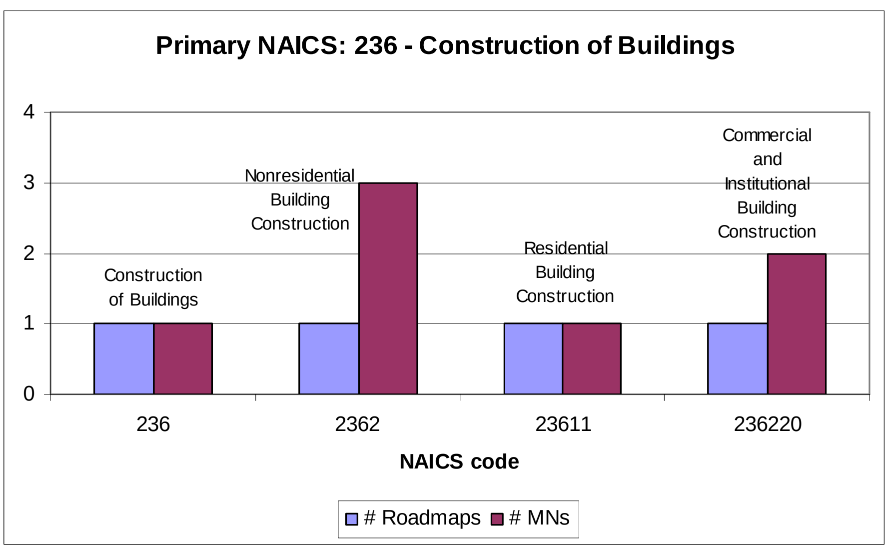
GUIDE TO NAICS MAPS

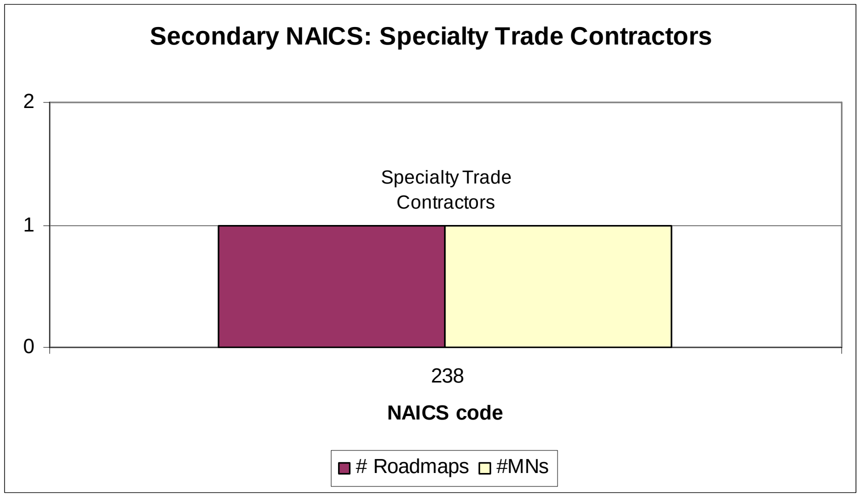

Primary NAICS: Agriculture, Forestry, Fishing, and Hunting
2
1
0
Crop Production
Support Activities for Forestry
111
115310
NAICS code
Roadmaps
MNs


Primary NAICS: 112 - Animal Production
2
1
0
Animal Production
Animal Aquaculture
112
11251
NAICS code
Roadmaps
MNs

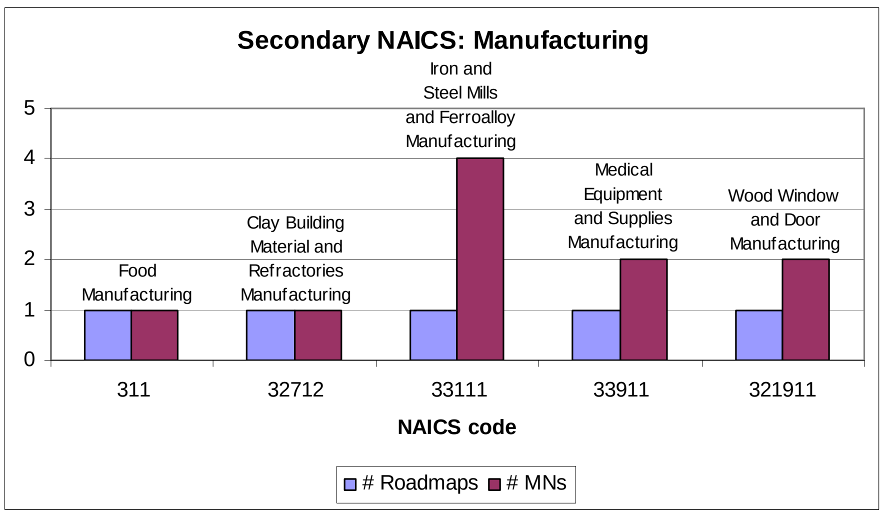

Primary NAICS: Mining
2
1
0
Mining
(except Oil
and Gas)
Support
Activities
for Metal
Mining
212
213114
NAICS code
Roadmaps
MNs


Primary NAICS: 221 - Utilities
6
5
4
3
2
1
0
Utilities
Electric Power
Generation,
Transmission,
Distribution
Water,
Sewage,
and Other
Systems
Electric Power
Transmission,
Control,
Distribution
Fossil Fuel
Electric
Power
Generation
Nuclear
Electric
Power
Generation
221
2211
2213
22112
221112
221113
NAICS code
Roadmaps
MNs

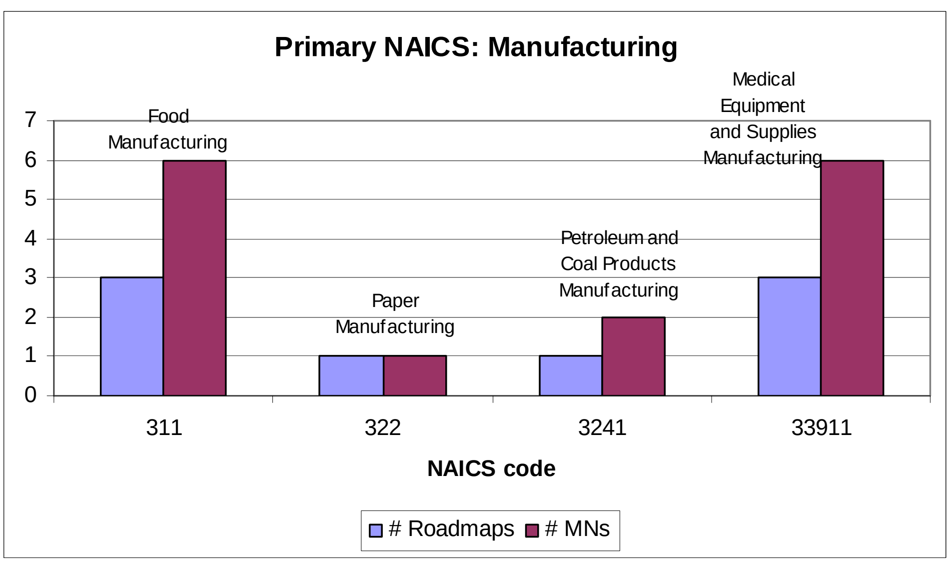

Primary NAICS: 236 - Construction of Buildings
4
3
2
1
0
Construction
of Buildings
Nonresidential
Building
Construction
Residential
Building
Construction
Commercial
and
Institutional
Building
Construction
236
2362
23611
236220
NAICS code
Roadmaps
MNs



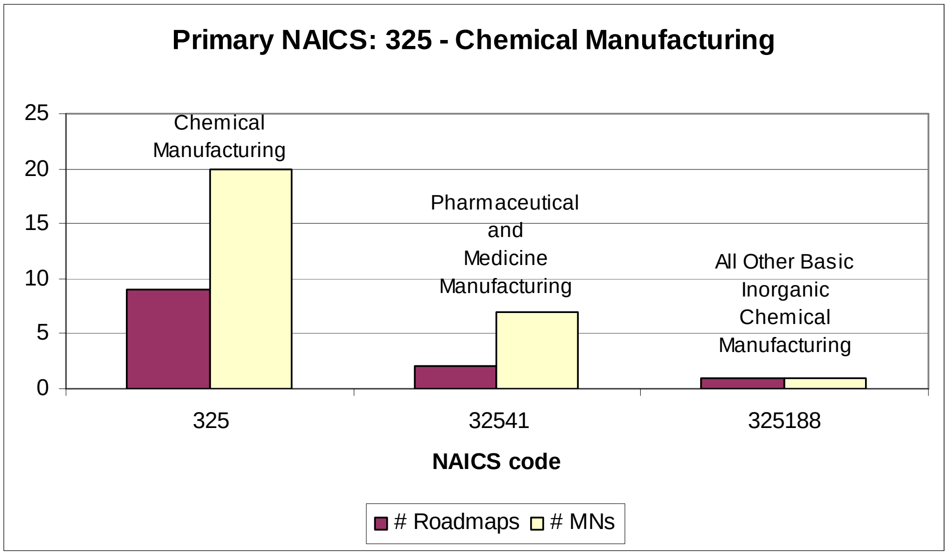
Secondary NAICS: Specialty Trade Contractors
2
1
0
Specialty Trade Contractors
238
NAICS code
Roadmaps
#MNs

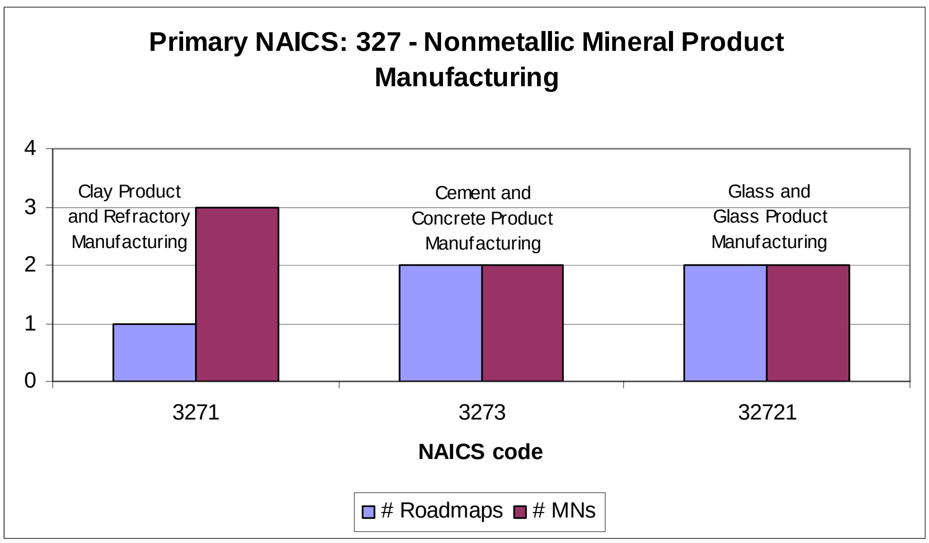


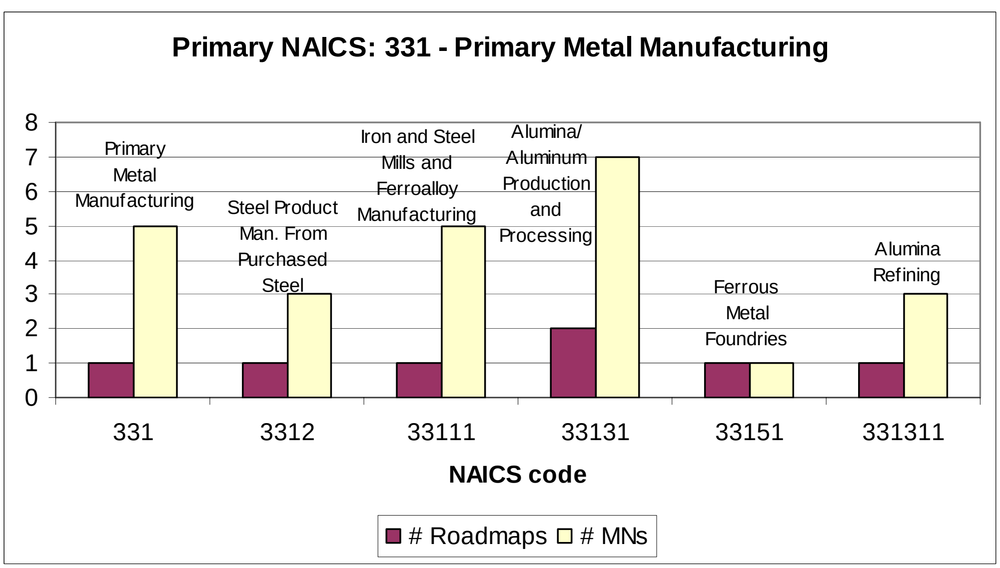
Secondary NAICS: Manufacturing
5
4
3
2
1
0
Food Manufacturing
Clay Building Material and Refractories Manufacturing
Iron and Steel Mills and Ferroalloy Manufacturing
Medical Equipment and Supplies Manufacturing
Wood Window and Door Manufacturing
311
32712
33111
33911
321911
NAICS code
Roadmaps
MNs

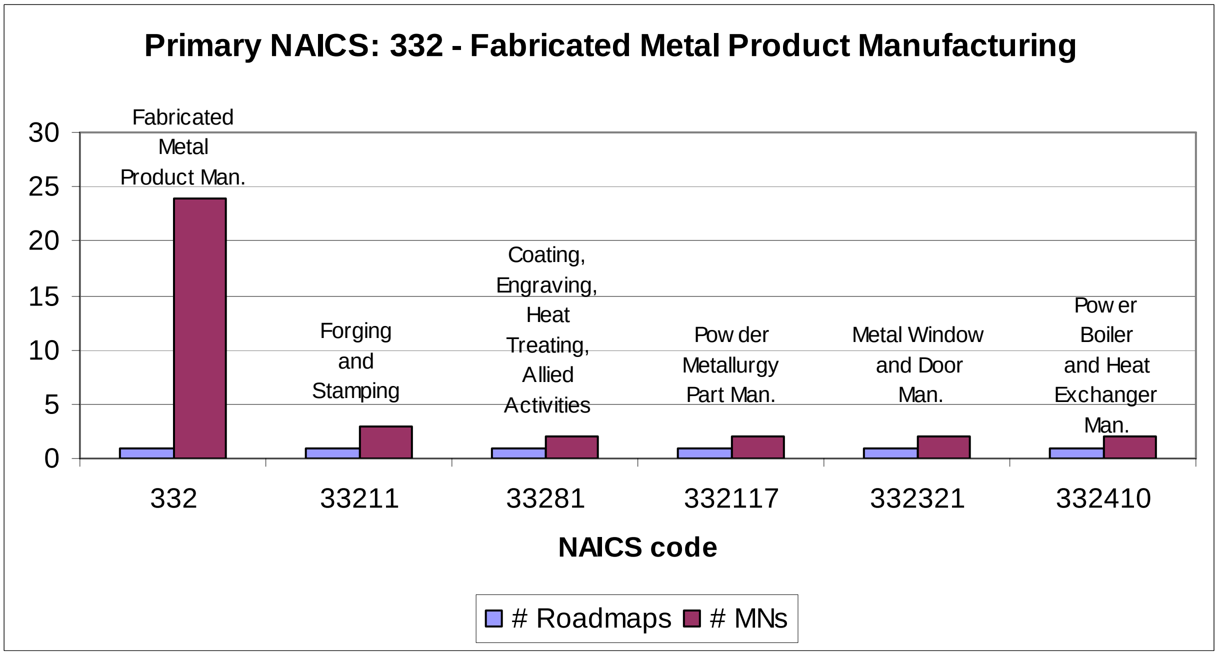


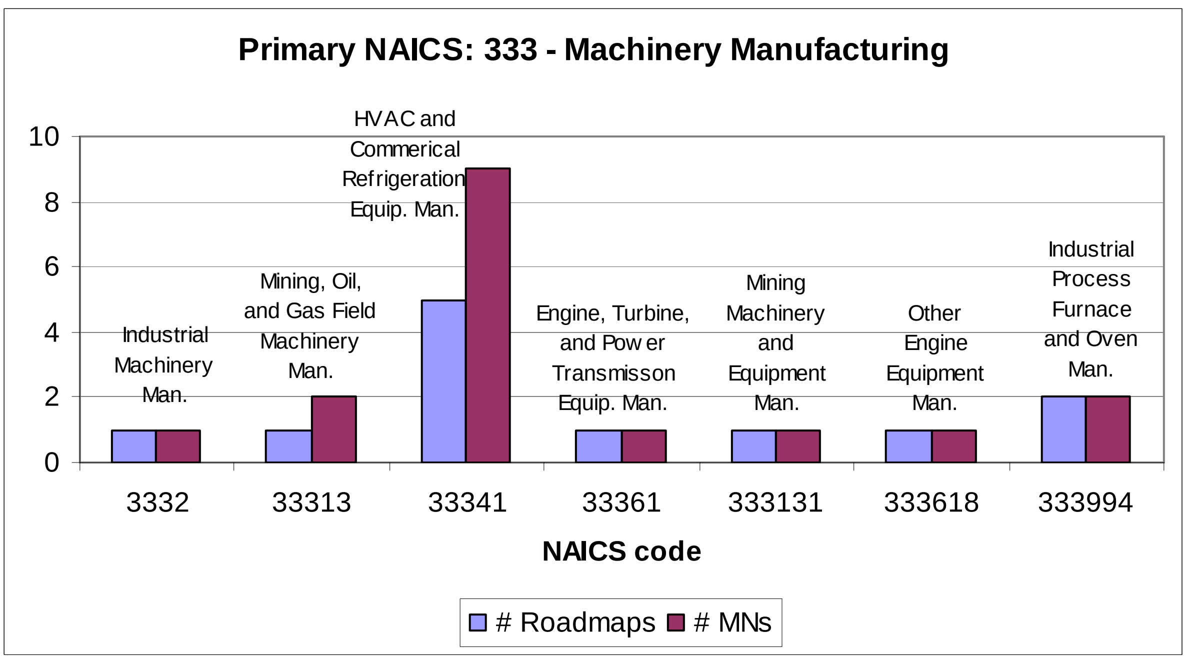
Primary NAICS: Manufacturing
7
6
5
4
3
2
1
0
Food Manufacturing
Paper Manufacturing
Petroleum and Coal Products Manufacturing
Medical Equipment and Supplies Manufacturing
311
322
3241
33911
NAICS code
Roadmaps
MNs

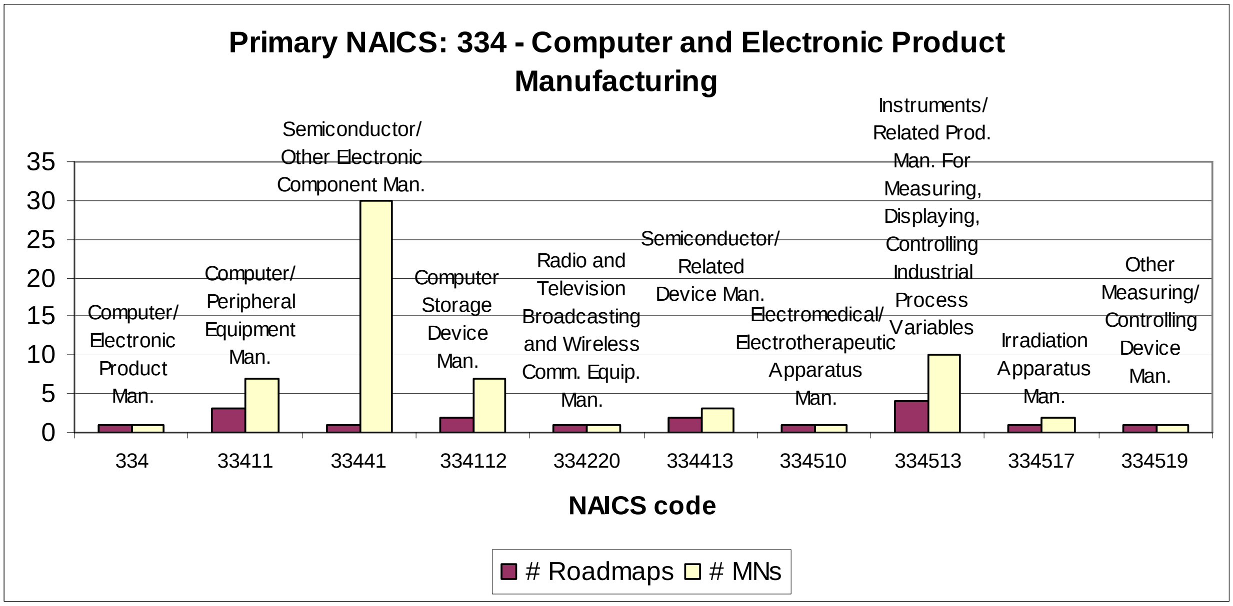

Primary NAICS: 325 - Chemical Manufacturing
25
20
15
10
5
0
Chemical Manufacturing
Pharmaceutical and Medicine Manufacturing
All Other Basic Inorganic Chemical Manufacturing
325
32541
325188
NAICS code
Roadmaps
MNs

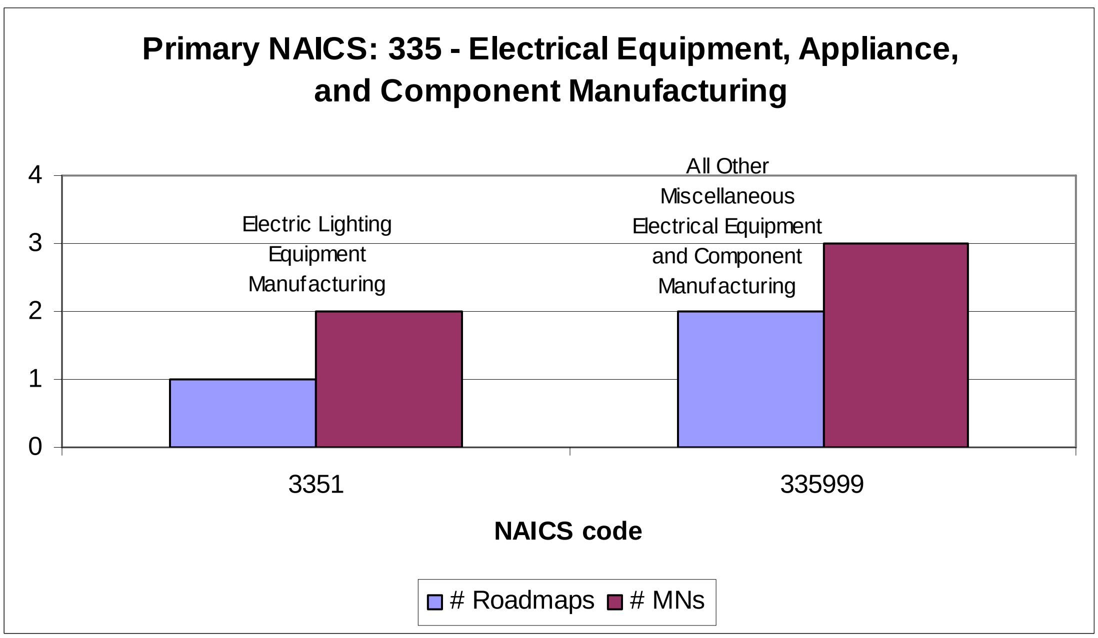

Primary NAICS: 327 - Nonmetallic Mineral Product Manufacturing
4
3
2
1
0
Clay Product and Refractory Manufacturing
Cement and Concrete Product Manufacturing
Glass and Glass Product Manufacturing
3271
3273
32721
NAICS code
Roadmaps
MNs

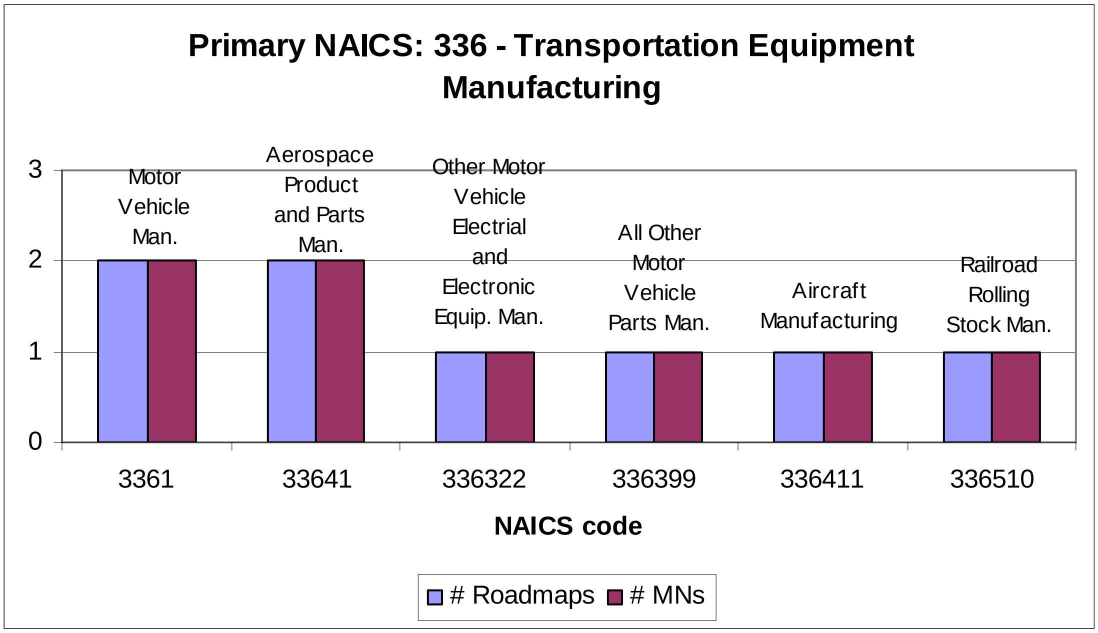

Primary NAICS: 331 - Primary Metal Manufacturing
8
7
6
5
4
3
2
1
0
Primary Metal Manufacturing
Steel Product Man. From Purchased Steel
Iron and Steel Mills and Ferroalloy Manufacturing
Alumina/ Aluminum Production and Processing
Ferrous Metal Foundries
Alumina Refining
331
3312
33111
33131
33151
331311
NAICS code
Roadmaps
MNs

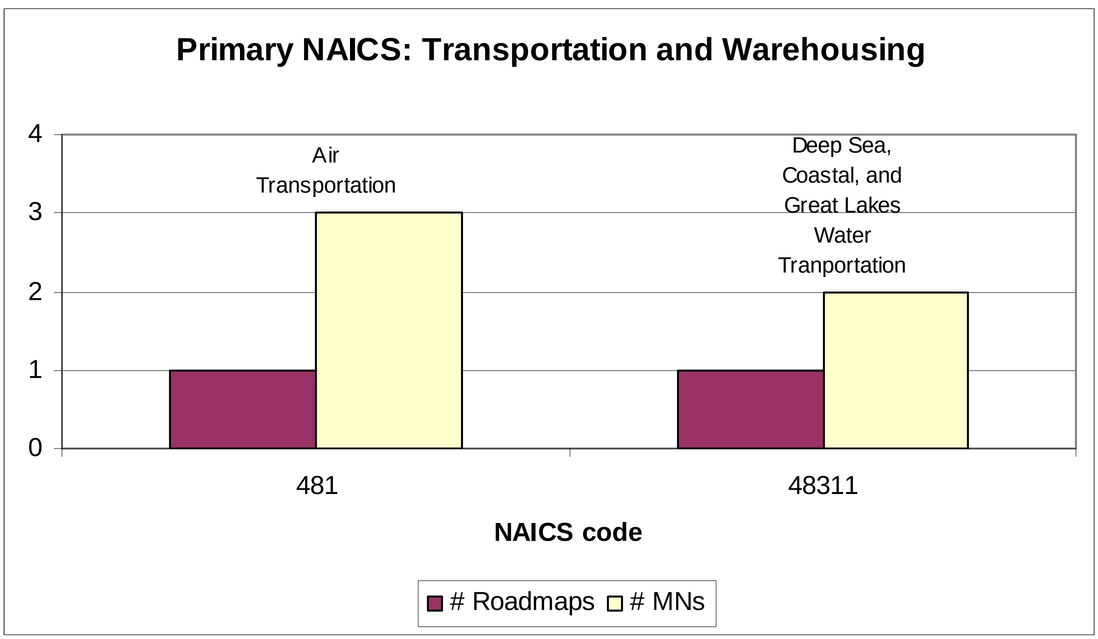

Primary NAICS: 332 - Fabricated Metal Product Manufacturing
30
25
20
15
10
5
0
Fabricated Metal Product Man.
Forging and Stamping
Coating, Engraving, Heat Treating, Allied Activities
Pow der Metallurgy Part Man.
Metal Window and Door Man.
Pow er Boiler and Heat Exchanger Man.
332
33211
33281
332117
332321
332410
NAICS code
Roadmaps
MNs

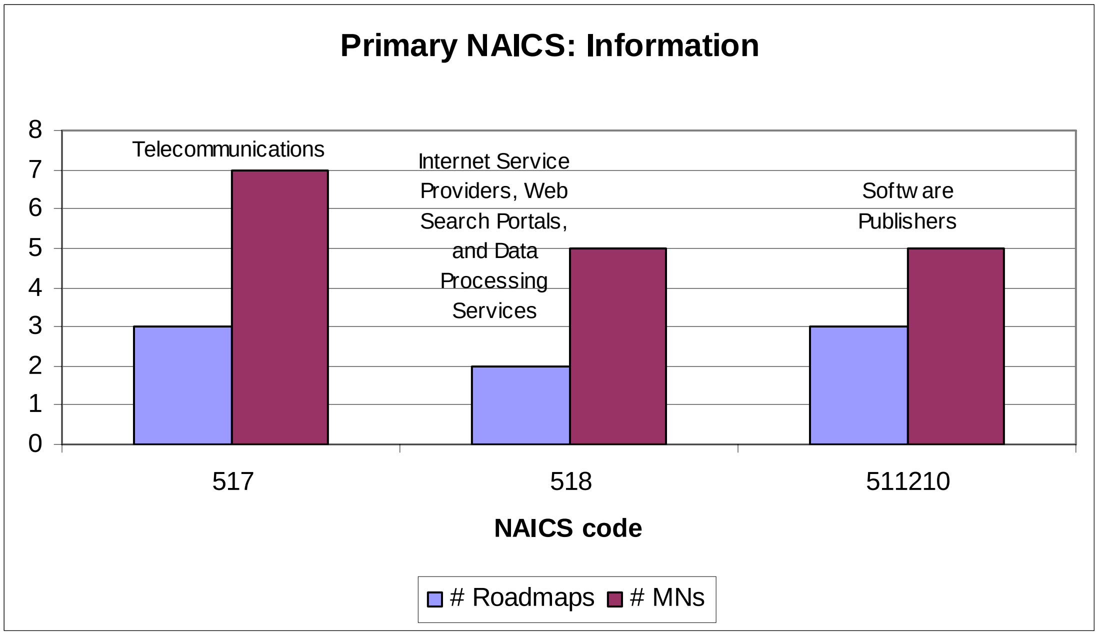

Primary NAICS: 333 - Machinery Manufacturing
10
8
6
4
2
0
Industrial Machinery Man.
Mining, Oil, and Gas Field Machinery Man.
HVAC and Commerical Refrigeration Equip. Man.
Engine, Turbine, and Pow er Transmisson Equip. Man.
Mining Machinery and Equipment Man.
Other Engine Equipment Man.
Industrial Process Furnace and Oven Man.
3332
33313
33341
33361
333131
333618
333994
NAICS code
Roadmaps
MNs

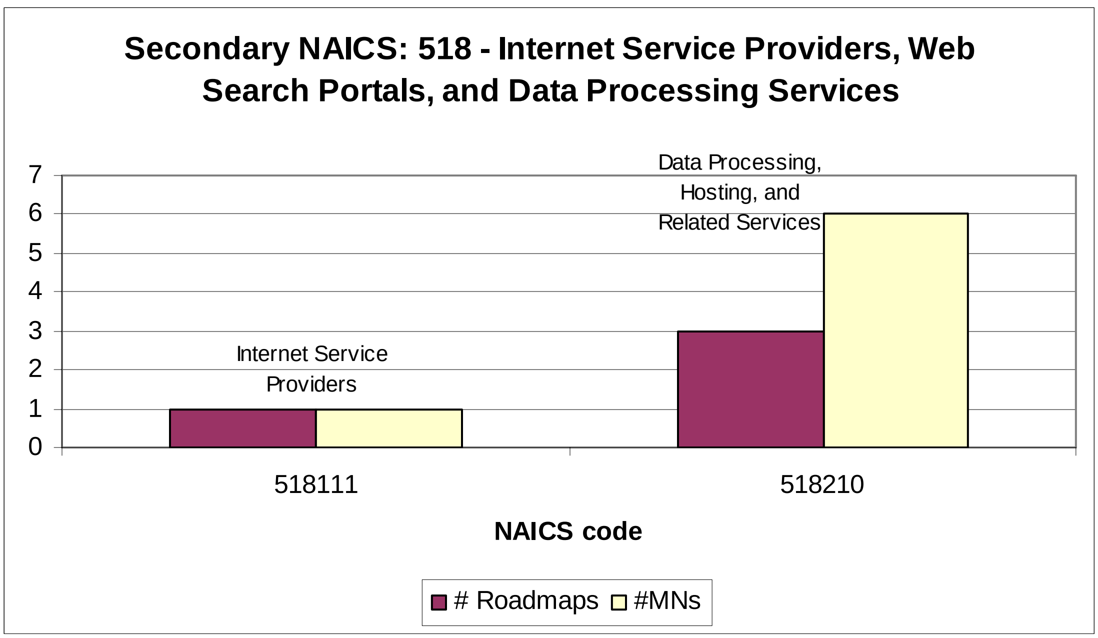

Primary NAICS: 334 - Computer and Electronic Product Manufacturing
35
30
25
20
15
10
5
0
Computer/ Electronic Product Man.
Computer/ Peripheral Equipment Man.
Semiconductor/ Other Electronic Component Man.
Computer Storage Device Man.
Radio and Television Broadcasting and Wireless Comm. Equip. Man.
Semiconductor/ Related Device Man.
Electromedical/ Electrotherapeutic Apparatus Man.
Instruments/ Related Prod. Man. For Measuring, Displaying, Controlling Industrial Process Variables
Irradiation Apparatus Man.
Other Measuring/ Controlling Device Man.
334
33411
33441
334112
334220
334413
334510
334513
334517
334519
NAICS code
Roadmaps
MNs

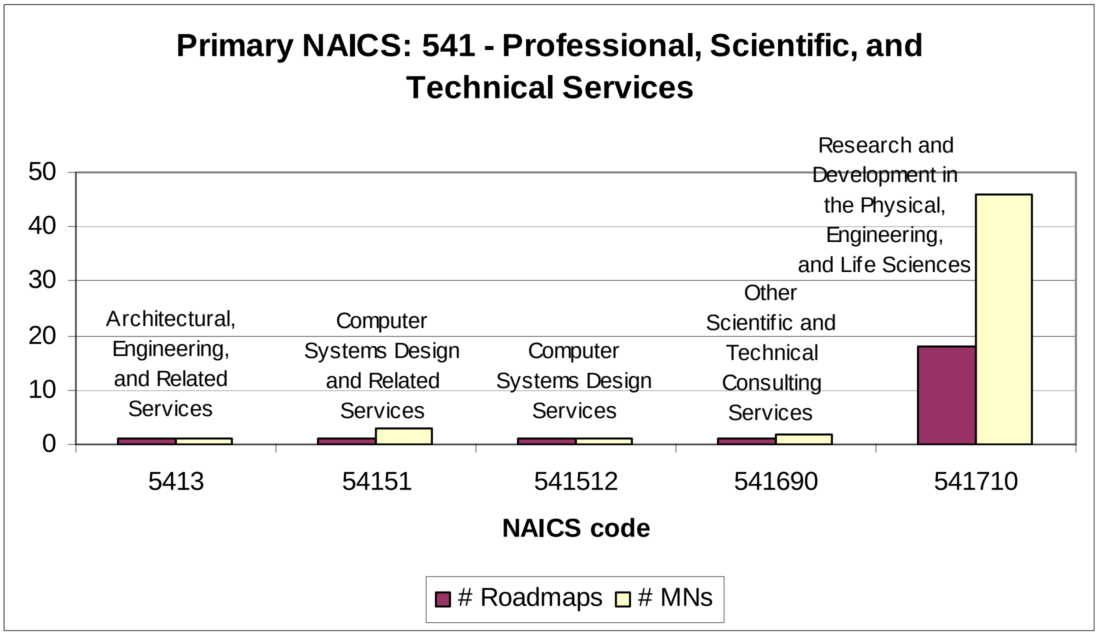

Primary NAICS: 335 - Electrical Equipment, Appliance, and Component Manufacturing
4
3
2
1
0
Electric Lighting Equipment Manufacturing
All Other Miscellaneous Electrical Equipment and Component Manufacturing
3351
335999
NAICS code
Roadmaps
MNs

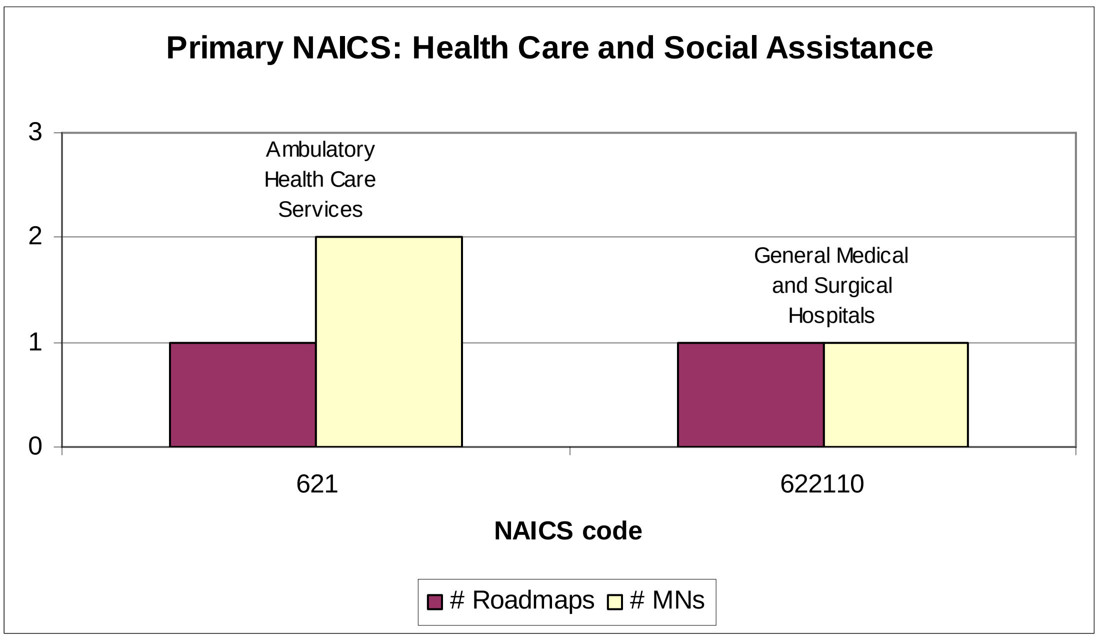

Primary NAICS: 336 - Transportation Equipment Manufacturing
3
2
1
0
Motor Vehicle Man.
Aerospace Product and Parts Man.
Other Motor Vehicle Electrial and Electronic Equip. Man.
All Other Motor Vehicle Parts Man.
Aircraft Manufacturing
Railroad Rolling Stock Man.
3361
33641
336322
336399
336411
336510
NAICS code
Roadmaps
MNs

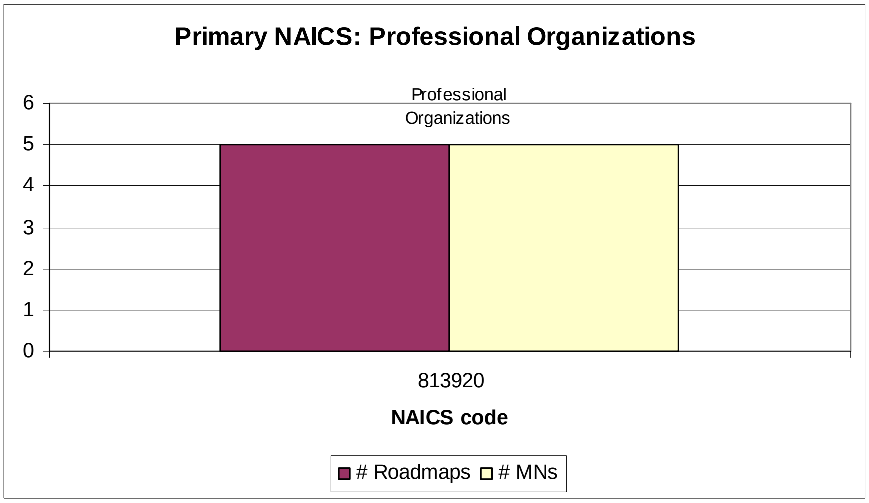

Primary NAICS: Transportation and Warehousing
4
3
2
1
0
Air Transportation
Deep Sea, Coastal, and Great Lakes Water Tranportation
481
48311
NAICS code
Roadmaps
MNs

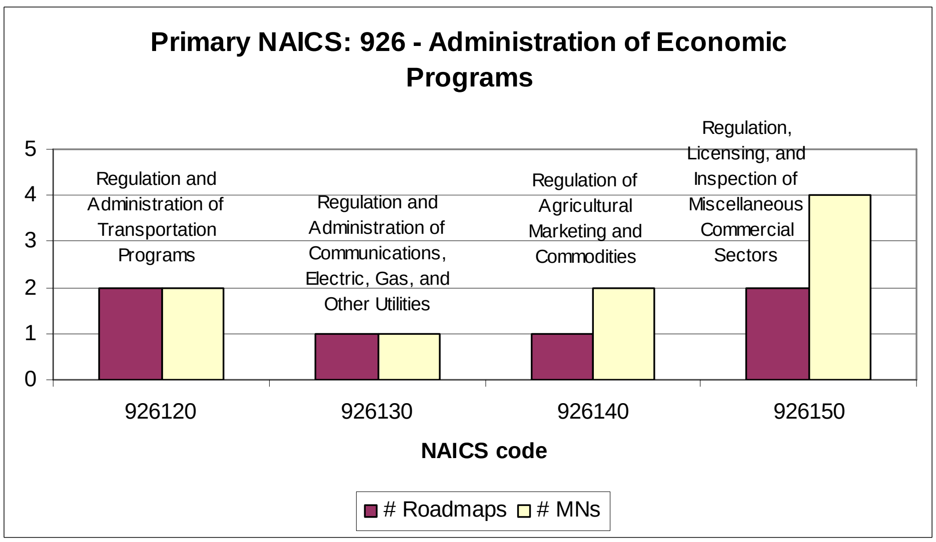

Primary NAICS: Information
8
7
6
5
4
3
2
1
0
Telecommunications
Internet Service Providers, Web Search Portals, and Data Processing Services
Softw are Publishers
517
518
511210
NAICS code
Roadmaps
MNs

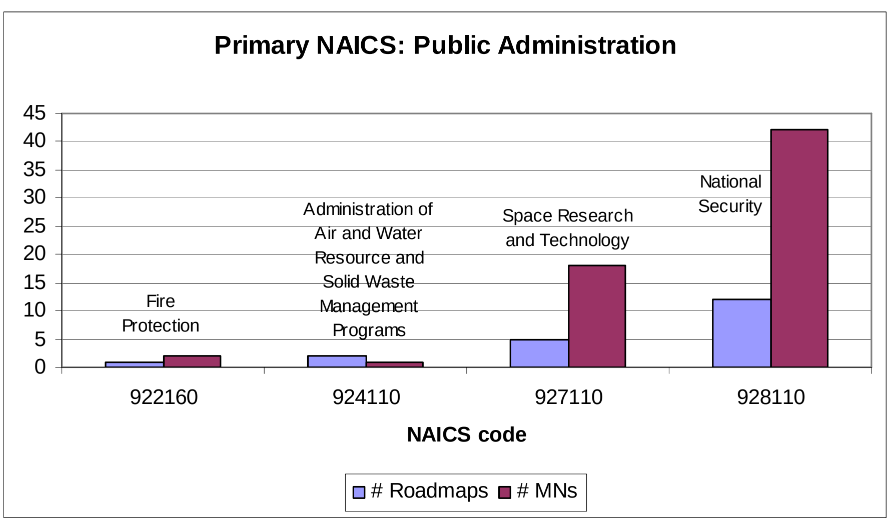

Secondary NAICS: 518 - Internet Service Providers, Web Search Portals, and Data Processing Services
7
6
5
4
3
2
1
0
Data Processing, Hosting, and Related Services
Internet Service Providers
518111
518210
NAICS code
Roadmaps
#MNs


Primary NAICS: 541 - Professional, Scientific, and Technical Services
50
40
30
20
10
0
Architectural, Engineering, and Related Services
Computer Systems Design and Related Services
Computer Systems Design Services
Other Scientific and Technical Consulting Services
Research and Development in the Physical, Engineering, and Life Sciences
5413
54151
541512
541690
541710
NAICS code
Roadmaps
MNs


Primary NAICS: Health Care and Social Assistance
3
2
1
0
Ambulatory Health Care Services
General Medical and Surgical Hospitals
621
622110
NAICS code
Roadmaps
MNs


Primary NAICS: Professional Organizations
Professional Organizations
6
5
4
3
2
1
0
813920
NAICS code
Roadmaps
MNs


Primary NAICS: 926 - Administration of Economic Programs
5
4
3
2
1
0
Regulation and Administration of Transportation Programs
Regulation and Administration of Communications, Electric, Gas, and Other Utilities
Regulation of Agricultural Marketing and Commodities
Regulation, Licensing, and Inspection of Miscellaneous Commercial Sectors
926120
926130
926140
926150
NAICS code
Roadmaps
MNs


Primary NAICS: Public Administration
45
40
35
30
25
20
15
10
5
0
Fire Protection
Administration of Air and Water Resource and Solid Waste Management Programs
Space Research and Technology
National Security
922160
924110
927110
928110
NAICS code
Roadmaps
MNs